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Toxic and Hazardous Materials Agency

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FINAL REPORT

Evaluation of Aluminum Ion Vapor Deposition as a Replacement for Cadmium Electroplating at Anniston Army Depot

April 1992
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The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) conducts research and development projects with the objective of minimizing hazardous waste generation at Army Depots. During one such project, USATHAMA evaluated the feasibility of an Aluminum Ion Vapor Deposition System as an alternative to cadmium electroplating. The test program was conducted at Anniston Army Depot, Anniston, Alabama. IT Environmental Programs, Inc. was USATHAMA's contractor for this program.

The Aluminum Ion Vapor Deposition System, referred to herein as an Ivadizer, provides corrosion resistance to metal parts by depositing a thin aluminum film (typically 1 mil or 0.001 inch) on the parts. As a replacement for cadmium electroplating, the Ivadizer has the advantage of generating minimal quantities of hazardous wastes; whereas cadmium plating generates significant quantities of listed hazardous waste, and cadmium is toxic (and possibly carcinogenic).

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The Ivadizer melts, vaporizes, and ionizes aluminum in a partial vacuum. The positively charged ions are attracted to the negatively charged metal surface of the part. Aluminum coatings are equal or superior to cadmium electroplates with respect to coating adherence, corrosion protection and uniformity of thickness. Most of the more than 70 Ivadizers now in successful service are used on parts for military and commercial aircraft. This report describes the Ivadizer process and documents 86 parts used on Army vehicles and engines, as well as nuts, bolts, brackets, and other small parts that were successfully aluminum-plated.

An Ivadizer coating requires significantly more force or torque to make a threaded connection than does a cadmium-coated fastener (a nut and bolt is a typical fastener). This is the most significant difference between these platings. Torques established for cadmium-coated fasteners can be used for aluminum-plated fasteners if the connections are lubricated (cetyl alcohol or molybdenum disulfide are effective) or if one member of the fastener (usually the nut) is cadmium plated. Alternatively, separate torque requirements could be established for aluminum-coated fasteners.

The Ivadizer can coat only to a depth of one diameter into a recess or cavity. Whereas this depth is equal or superior to conventional cadmium electroplating, electroplating offers the option of plating with an anode inside the part, which provides satisfactory cadmium plating on the interior. Very few parts processed at Anniston Army Depot would require special handling to overcome this disadvantage.

The capital cost of an Ivadizer system is estimated to be about 70 percent higher than that for an equivalent cadmium-plating system, and annual costs are estimated to be about 50 percent higher. The Ivadizer is a new and developing technology and equipment and procedures have been and are being developed that promise more efficient operation and lower costs. On the other hand, cadmium electroplating is a mature technology with limited potential for process improvements, and it is likely to face increasingly more stringent regulatory requirements. Thus, the cost differences between the Ivadizer and cadmium electroplating may be reduced in the future.

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SECTION 1

INTRODUCTION

1.1 Background

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) conducts research and development projects in support of the Army's goal to minimize the generation of hazardous wastes at Army depots. One such project involved demonstration testing of an Aluminum Ion Vapor Deposition System (hereinafter referred to as an Ivadizer) at the Anniston Army Depot (ANAD), Anniston, Alabama. The objective of this test was to evaluate the concept of replacing cadmium electroplating, which generates significant quantities of hazardous wastes, with aluminum ion vapor deposition, which generates almost no waste. The patented Ivadizer is manufactured solely by Abar Ipsen Industries of Rockford, Illinois. The technology was originally developed by McDonnell-Douglas Corporation for use on aircraft parts. The Ivadizer deposits a thin (typically 1-mil or 0.001-inch) aluminum coating on metal parts to protect them from corrosion.

Cadmium electroplating is used on many metal parts to provide a protective, corrosion-resistant finish. Cadmium plating offers good corrosion resistance in salt-water environments, provides a good base for soldering, and has a low coefficient of friction that gives cadmium-plated parts good threaded connections with low applied torque. Cadmium is a toxic, carcinogenic metal, however, and cadmium electroplating generates cadmium- and cyanide-containing sludges, rinse waters, and spent plating solutions that are listed hazardous wastes. Treatment of the rinse water and spent solutions also generates hazardous waste sludges that require special disposal. The aluminum Ion Vapor Deposition (AIVD) process does not generate hazardous waste; however, a relatively small volume of caustic waste is generated during periodic cleaning of the unit and its components. Based on these facts, replacing cadmium electroplating with AIVD would significantly reduce the volume of hazardous waste generated during plating operations.

If the Ivadizer technology were to replace cadmium electroplating at ANAD, it would reduce or eliminate 1) employee exposure to cadmium and cyanides, 2) the expense of treating cadmium and cyanides in spent plating solutions and rinse waters, and 3) the expense and potential liability associated with the disposal of cadmium- and cyanide-containing hazardous wastes.

1.2 Process Description

The operating principle of the Ivadizer is based on deposition of positively charged aluminum ions onto a clean, negatively charged, metal surface. Figure 1-1 is a schematic representation of the Ivadizer and the parts rack support systems. After parts are placed in the unit, the chamber is evacuated to reduce the air pressure to a maximum of 9×10^{-5} Torr. Argon gas is then introduced to raise the pressure to about 6×10^{-3} Torr (6 μm). A high-voltage discharge is used to ionize some of the argon to produce positive ions that bombard the negatively charged metal surface and provide final cleaning. After the Argon cleaning, pure aluminum wire is fed into ceramic, electrical-resistance heaters called "boats," where the wire is melted and vaporized. The boats move through the chamber to provide even distribution of the aluminum. The aluminum vapor is ionized by transfer of a positive charge from the argon ions. Aluminum ions are then attracted to the metal surface and deposited as a thin metal film. When aluminum parts are coated in the Ivadizer, nitrogen gas is introduced into the chamber during the operation to cool the aluminum parts to preserve their temper.

Both the boat speed and the wire feed rate control plating thickness; these are typically expressed as percentages of the maximum possible speed or rate. An Ivadizer is usually operated at a boat speed of 50 to 100 percent of maximum and a wire feed rate of 35 percent maximum. Parts being plated are either placed in a metal mesh barrel and tumbled during the plating process (barrel coating) or suspended from a rack by wires or other support, depending on the size and configuration of the part being coated (Figure 1-2). Figure 1-3 is a photograph of an Ivadizer and its control panel. Figure 1-4 shows an Ivadizer with the chamber door open and a barrel coating rack in place.

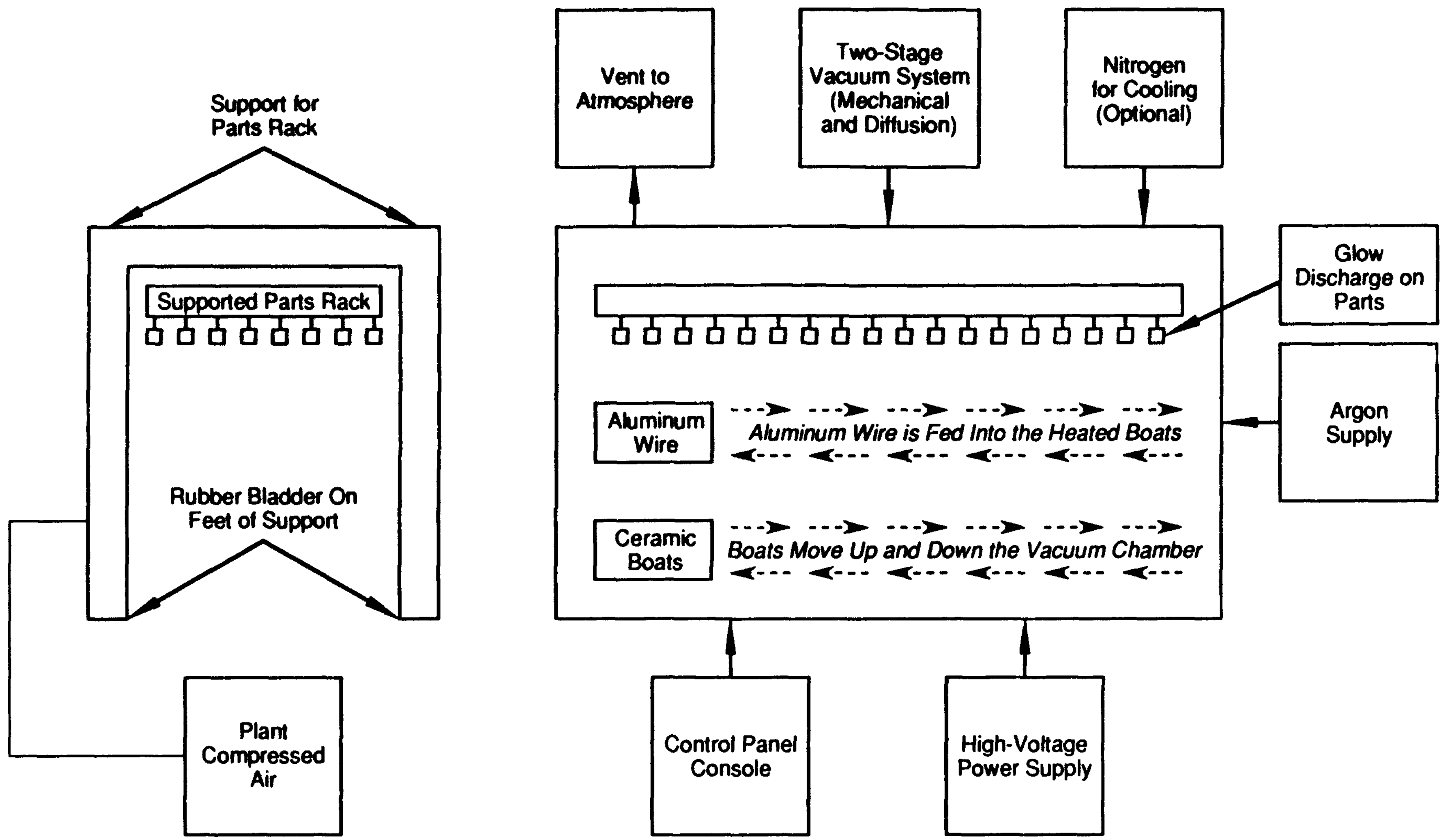

Figure 1-1. Schematic representation of an Ivadizer and the parts rack support systems.

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Figure 1-2. Plating rack with parts suspended from the rack.

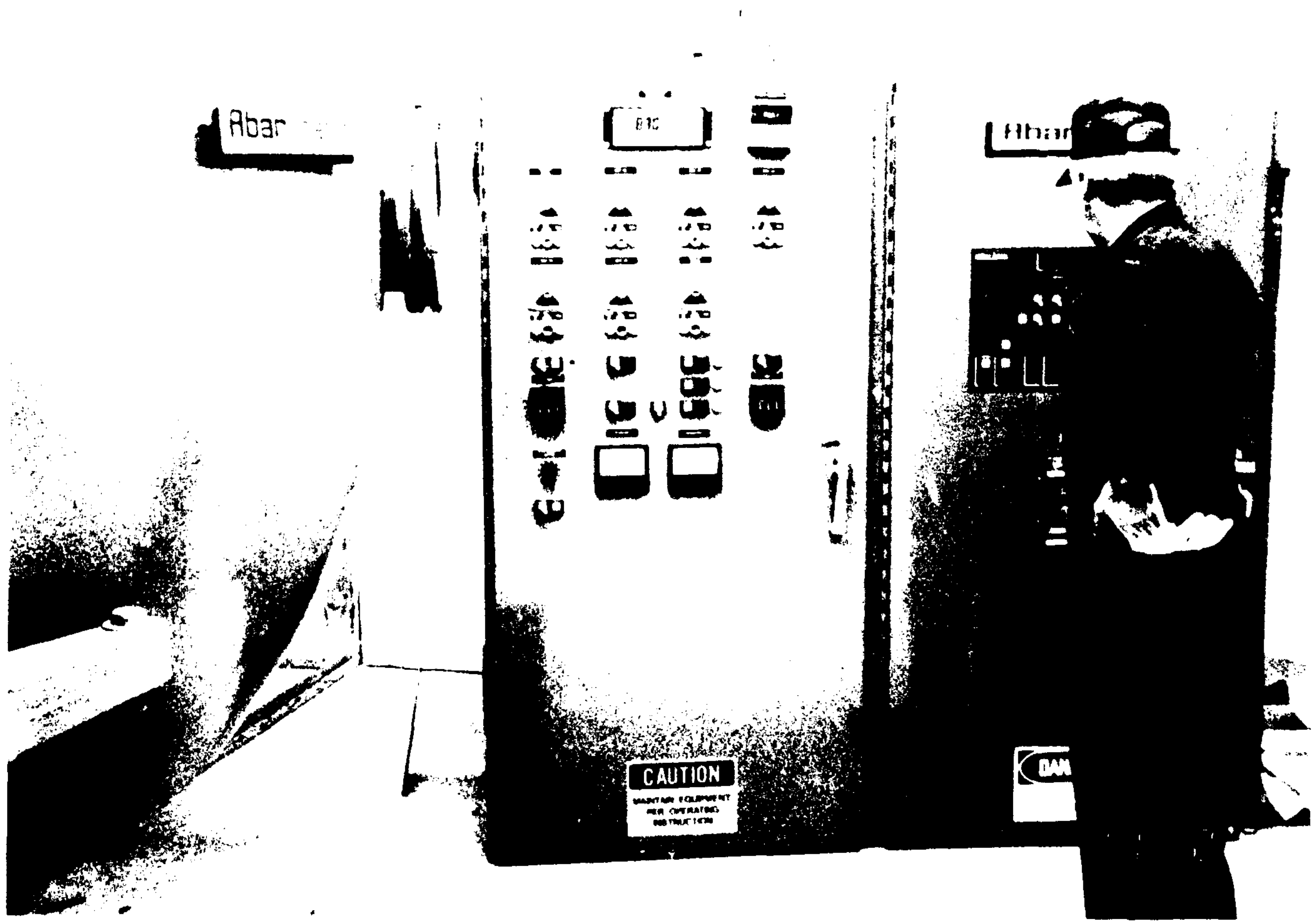

Figure 1-3. Ivadizer and the control panel.

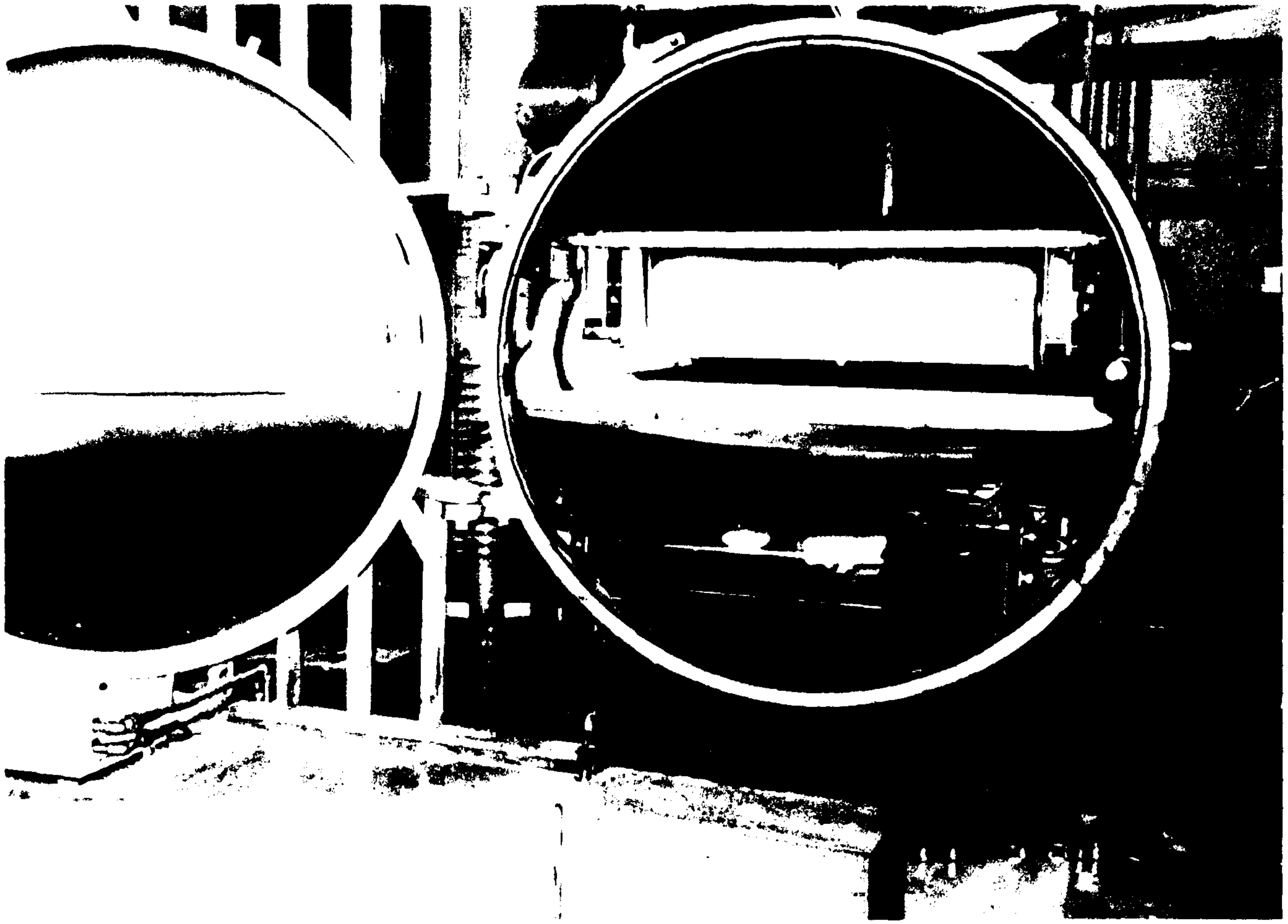

Figure 1-4. An Ivadizer with the chamber door open and a barrel coating rack in place.

Metal surfaces must be cleaned thoroughly before plating to achieve satisfactory adherence of the aluminum coating. All prior coatings, oil, and other organic matter must be removed from the surface of the part, and the metal surface must be prepared for plating by grit blasting. When handling parts prior to processing, Ivadizer operators must wear gloves to avoid contaminating the metal surfaces with body oils.

More than 70 Ivadizer units are currently in successful commercial operation. Most applications involve the plating of aircraft parts with a pure aluminum coating laid over an aluminum-alloy substrate to provide corrosion protection. In addition, this technology can be used to plate other metal substrates.

1.3 Scope and Objectives

The objective of this project was to determine if aluminum ion vapor deposition is a viable process to replace cadmium electroplating at U.S. Army depots. This objective was met by evaluating a full-scale AIVD production unit at Anniston Army Depot. During the demonstration tests at ANAD, various metal coupons and parts were plated and evaluated. Descriptions of optimized operational techniques were also compiled on processes used at a successful commercial AIVD installation. In addition, torque requirements for plated fasteners (the most significant difference between aluminum- and cadmium-plated parts) were evaluated.

SECTION 2

CURRENT USE OF IVADIZERS

2.1 Military and Commercial Aircraft Applications

The Navy has used Ivadizers at the Jacksonville and Pensacola Naval Air Stations to coat aircraft parts for more than 3 years. Parts used in marine environments are plated with aluminum for corrosion protection because such coatings last more than twice as long as cadmium coatings. Also, the Ivadizer is more effective in coating corners and recessed areas than is cadmium electroplating.

Over the past 10 years, the Ivadizer technology also has been used successfully by other organizations. The U.S. Army has aluminum-coated depleted uranium; Westinghouse has coated powerplant steam turbine blades; Douglas Aircraft and United Airlines have used Ivadizer coatings on DC-10 aircraft; and McDonnell has used Ivadizer coatings on F-4, F-15E, F-18, and AV-88 aircraft. Additionally, Boeing, Pratt and Whitney, SPS Technologies, ACF Industries, and Hi Shear have successfully used Ivadizer coatings for parts in field service. More than 70 Ivadizers are currently in operation in both commercial and military applications.

2.2 Process Optimization Based on Commercial Applications

One of the five commercial plating job shops that operate an Ivadizer was visited during this project.[1] This shop, Titanium Finishing Co., has developed practices and procedures independent of the technology used by McDonnell-Douglas and Abar Ipsen. Shop personnel at Titanium Finishing believe that their methods of operation allow the company to plate parts more economically while still achieving satisfactory quality. Many of these practices could be used by ANAD to improve both productivity and quality. These improvements can be categorized as procedural changes and capital improvements. A detailed discussion of these changes is presented in the following subsections to give ANAD and others the benefit of Titanium Finishing's experience.

2.2.1 Procedural Changes

Procedural changes are operational modifications that can be easily implemented at a relatively low cost. Several procedural changes have been implemented by Titanium Finishing, as described here.

2.2.1.1 Parts Racking

Titanium Finishing has modified the parts racks by permanently attaching alligator clips to effect a significant increase in the number of parts that can be processed in a single run (Figures 2-1, 2-2, and 2-3). This modification speeds up loading and unloading operations. The rack supplied with an Ivadizer holds a maximum of 392 parts; with the addition of alligator clips, the number of parts processed can be doubled or tripled. Additionally, the permanently fixed clips practically eliminate electrical shorting in the Ivadizer plating rack. The clips, however, can leave marks on some parts, such as washers. This problem can be eliminated by using notched rods to hold such parts.

Placement of parts on the racks can affect plating quality and thickness. Parts should not be placed within the shadow of another part as seen from the line of sight from the boats to the parts. Any cavities in the parts should be aligned so they are facing the boats. The last 2 inches on each side of the plating rack are not used by Titanium Finishing because the coating applied at this location has been found to be too thin when the rack is fully loaded.

2.2.1.2 Boat Control

Coating thickness is partially determined by the speed at which the boat passes through the chamber. The Ivadizer's control panel includes a boat speed control that does not indicate plating time directly; rather, it indicates boat speed as a percentage of maximum speed. Measurement of actual plating time provides better process control than does monitoring of boat speed alone.

The position of the boat in relation to the part also is an important factor in determining plating thickness and quality. Titanium Finishing has found that a

Figure 2-1. Unloaded plating rod showing the position of the alligator clamps.

Figure 2-2. Loaded plating rod showing the attachment of the plating rod to the fixed hooks on the parts rack.

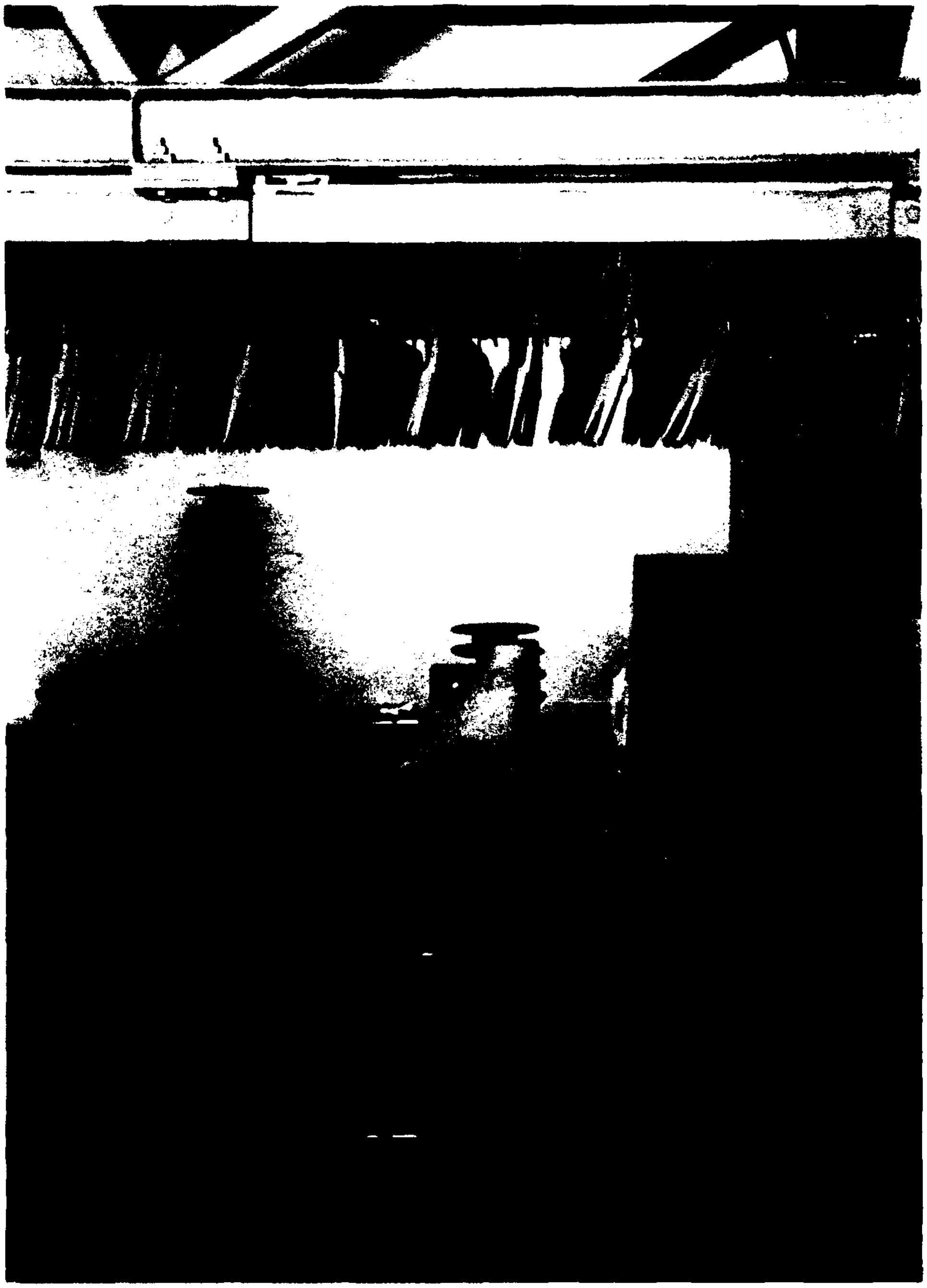

Figure 2-3. Plating rods loaded and attached to the rack.

potentiometer can be added to the boat control and calibrated to specific positions in the chamber. This allows the operator to position the plating boats precisely. This precision is especially important during barrel coating, which requires the boats to be positioned directly beneath the barrel.

2.2.1.3 Wire Feed Rate

The manufacturer states that 35 percent of the maximum wire feed rate is the most desirable setting for almost all applications. Titanium Finishing has found that a 50 percent wire feed rate provides more aluminum for plating without increasing plating time. However, operating at increased wire feed rates requires more operator control. Experienced operators can run the system effectively at a 55 percent wire feed rate, which could increase production rates even more.

2.2.1.4 Employee Utilization

Titanium Finishing can process six loads in an 8-hour shift rather than the two to three loads achievable with the manufacturer's procedures. Cleaning and shotblasting take two-thirds of the labor hours required to operate their system. Therefore, six employees are required to achieve six runs in an 8-hour shift: four to clean and shotblast parts and two to load and unload the plating racks and operate the Ivadizer. Each of the six employees is trained to perform all of the Ivadizer operations (cleaning, shotblasting, plating, etc.), and their activities are coordinated so that plating time in the Ivadizer chamber controls the production rate.

2.2.1.5 Cleaning Internal Shields

Removable internal shields in the Ivadizer chamber block the flow of aluminum vapor to protect the boat clamps, electrodes, wire feed mechanisms, and chamber walls. Accumulated aluminum is periodically removed from the shields with a caustic solution. The spent caustic solution from this cleaning is a corrosive waste. This waste generation can be minimized by painting a slurry of boron nitride (which serves as a release agent) on the Ivadizer shields (Figure 2-4).

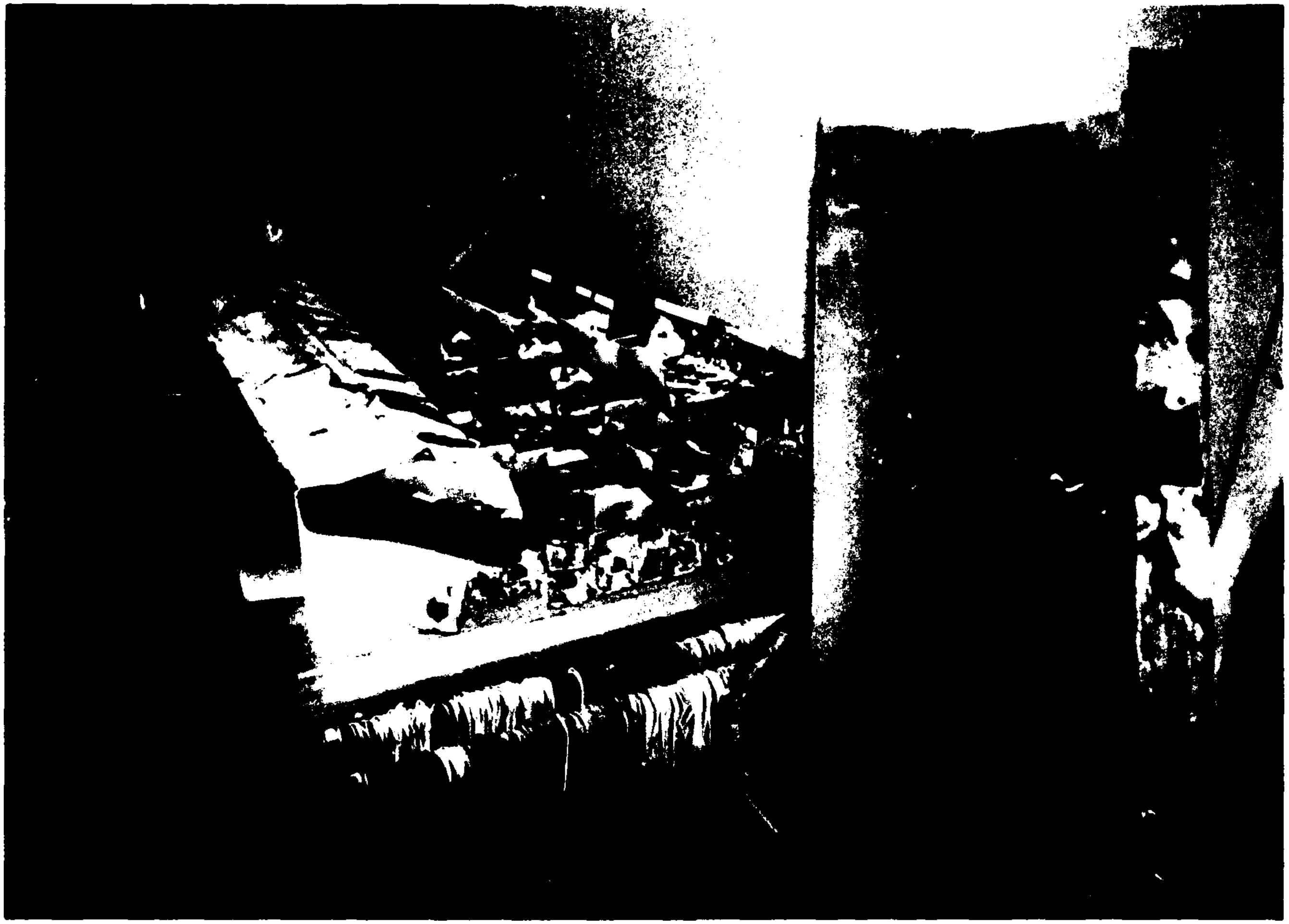

Figure 2-4. Ivadizer boat shields showing the boron nitride release agent. (The shields are on the table and inside the drum.)

Aluminum accumulations on treated shields can be easily removed without caustic stripping. The boron nitride treatment cannot be used, however, where aluminum could fall off the shields and into the boats, as this would interfere with the boat operation. Overall, the use of boron nitride reduces the frequency and amount of chemical cleaning required.

2.2.1.6 Barrel Coating

The Ivadizer barrel coater (Figure 1-4), which is adapted from conventional electroplating technology, is used to coat nuts, bolts, and other small parts when it is inefficient to handle each piece separately. The barrel, an open-mesh cylinder, is rotated to produce a tumbling action which exposes all metal surfaces to the aluminum ions. The barrel rack, like other parts racks, is supported on air flotation pads which allow easy transport and positioning of the carts.

Rack coating is reportedly superior to barrel coating for most applications. Additionally, barrel coating has the following disadvantages:

- Parts can be damaged when they tumble against each other. (At least 30 barrel rotations are required for uniform coating.)
- Larger parts can jam in the barrel coater.
- Coatings greater than 0.0005 inch thick (0.5 mil) cannot be applied because coating uniformity becomes unreliable.

Although the barrel coater supplied by Abar Ibsen includes two drums, better results have been obtained by Titanium Finishing when only one is used. During use, aluminum plates on the wire mesh that encases the barrel and decreases the dimensions of the mesh. This causes variations in plating thickness and results in aluminum deposits on the barrel coater that must be removed, preferably after each use.

2.2.2 Capital Improvements

The capital improvements discussed below improve production by removing water vapor, volatile organic compounds, and, to a lesser extent, oxygen from the plating chamber. This reduces pump-down time (chamber evacuation) and increases the production rate.

2.2.2.1 Cryogenic Unit

A two-stage vacuum pump system is required to achieve an absolute air pressure of $9x10^{-5}$ Torr in the Ivadizer chamber. The first-stage mechanical pump reduces air pressure to about $1x10^{-3}$ Torr. At that point, the second-stage oil-diffusion pump takes over to achieve the target vacuum. Significantly more time and energy are required to achieve the target vacuum if water vapor is present. To remove water vapor, a cryogenic refrigeration unit can be installed (approximately $50,000 to retrofit the unit at ANAD or $35,000 as original equipment). This unit pumps cold refrigerant (-120°F typical) through a copper coil located inside the Ivadizer chamber. Water vapor present in the chamber condenses onto the coil as ice. Operation of a cryogenic unit can be as effective as adding a second diffusion pump in reducing pump-down time. Addition of a cryogenic unit increases the number of runs that can be made during a shift and improves coating quality.

2.2.2.2 Venting

At the completion of each run, the chamber is vented to relieve the vacuum. Venting the chamber with nitrogen rather than room air minimizes the amount of water vapor in the system. As discussed previously, this reduces pump-down time. Nitrogen venting requires a liquid-nitrogen supply, a nitrogen evaporator, and associated connections (about $15,000 as a system retrofit).

2.2.2.3 Climate Control

The manufacturer recommends that the room housing the Ivadizer be air conditioned. Additionally, humidity control, electrostatic dust controls, and a positive pressure in the Ivadizer room (about $3,000 worth of modifications) further enhance operations by reducing the presence of airborne contaminants and water vapor.

2.2.2.4 Parts Rack Modifications

The manufacturer-supplied plating rack includes horizontal support rods that are rotated by a chain drive. This system can be used to plate large cylinders. Cylinders are positioned on the horizontal rods and rotated continuously during the plating process to ensure a uniform coating. The rack can be modified to allow plating of larger parts by removing the chain drive and constructing an open, heavy frame (Figure 2-5). However, parts processed on this modified rack must be rotated manually, which requires that the part be processed multiple times. (ANAD's rotating rack could be modified for about $2,000, or a new rack could be purchased for $10,000.)

2.2.3 Operational Improvements

2.2.3.1 Discoloration on Ivadizer Parts

Presence of water vapor, organic contaminants (e.g., lubricants, degreasing agents, and dye penetrant materials), and oxygen in the Ivadizer can cause a light tan to brown or black coloration on freshly plated parts. Inadequate cleaning prior to processing can be a source of these contaminants and will impact plating quality. The source of such contamination often can be identified before the rack is unloaded by visually tracing the path of the discoloration from the source to the Ivadizer vent. Peening with glass beads will frequently remove discoloration and leave a metal surface that provides good protection. If the color is not removed by peening, the coating will probably be brittle, nonadhering, and provide little or no corrosion protection.

2.2.3.2 Plating Thickness

Thickness is controlled by plating time (as discussed under Boat Speed), distance from the boat, and the number of parts plated simultaneously. A thickness of 1 mil is the standard aluminum coating, compared with 0.3 mil for cadmium plating. This coating thickness provides better corrosion protection and requires little additional plating time or expense.

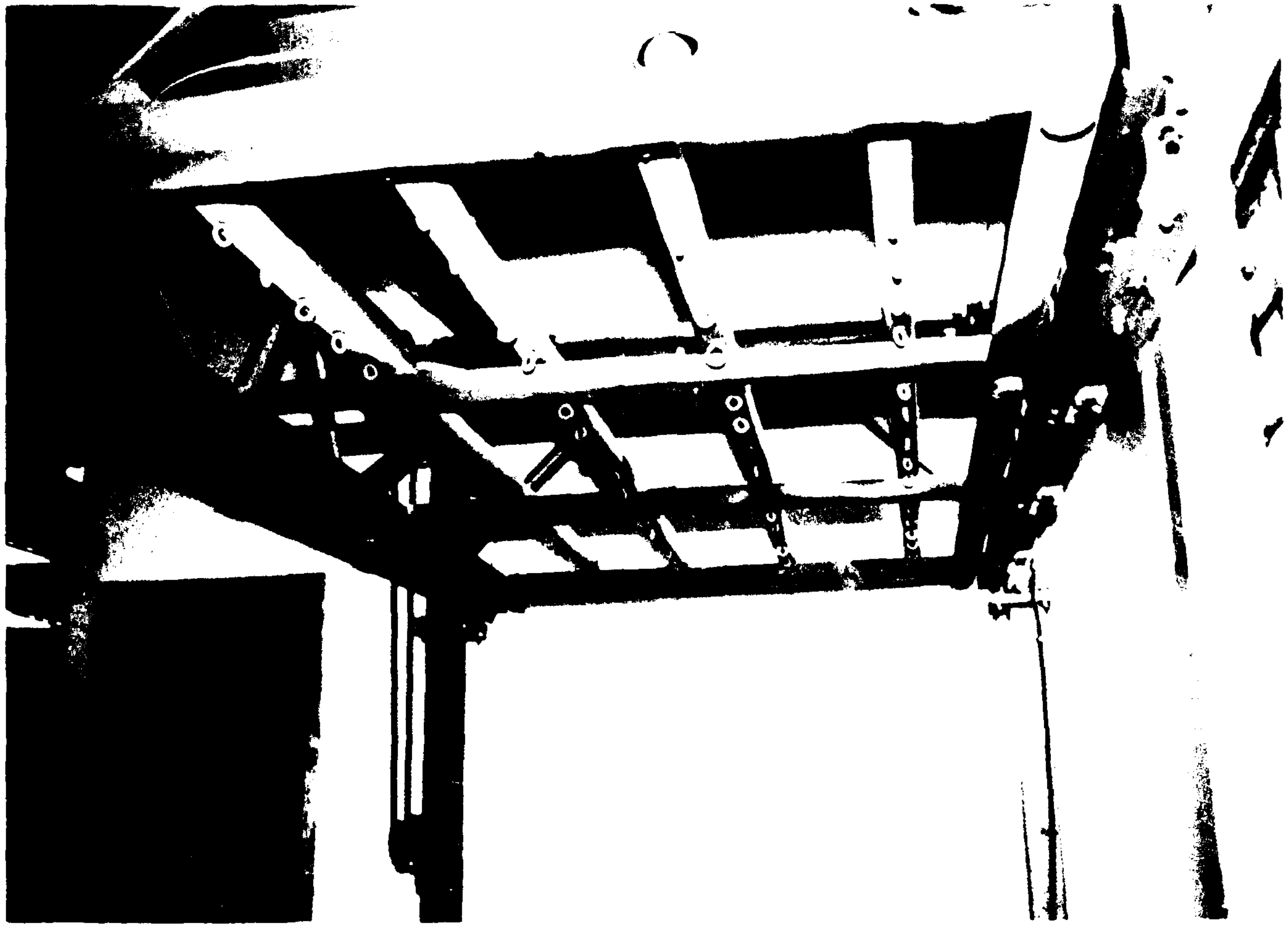

Figure 2-5. Modified rotatable plating rack showing epoxy supports and the heavy support structure.

Plating thickness decreases as the distance from the part to the aluminum boat increases. Titanium Finishing has found that parts hung as close as possible to the top of the plating rack exhibit fewer variations in plating thickness. They have also determined that loading the Ivadizer to half capacity will increase coating thickness by 10 percent as compared to the thickness achieved when a full load is processed. Minor variations in plating thickness (about 0.01 mil) may occur if the part is positioned near the vacuum pump outlet or if there is any hesitation in the movement of the boat through the chamber.

2.2.3.3 Plating Boat Life

The plating boats are made of titanium diboride and boron nitride. This material is slowly attacked by molten aluminum. Replacement is typically required after 7 to 10 hours of use. Additionally, thermal shock shortens boat life, but can be minimized by allowing gradual warm-up and slow cooling. Impending boat failure often can be predicted by an observed increase in amperage and the presence of hot spots. Boats typically are replaced when the boat amperage reaches 700 amps.

2.2.3.4 Quality Control Testing and Procedures

Parts from every load should be inspected and tested for coating thickness. Coating thickness on parts or steel test coupons should be measured using either a magnetic-type thickness gauge or a micrometer. Test coupons should be included during each run and should be frequently subjected to salt spray testing. Because glass bead peening after plating (a requirement of the Ivadizer process) is a more severe adhesion test than the typical bend test, the latter can often be eliminated.

The military specifications pertaining to chromate conversion coatings (applied over most aluminum and cadmium coatings), MIL-C-5541, require a 168-hour salt spray test. The appearance of discoloration or white-powder residue during testing of aluminum-coated parts does not necessarily indicate failure, since aluminum can oxidize and discolor. Therefore, analysis of the discoloration is required to determine if it is caused by corrosion of the base metal or oxidation on the aluminum plating.

2.2.3.5 Maintenance

Good maintenance practices include checking the oil in the vacuum pumps weekly and changing it annually; cleaning major boat shields when boats are replaced (replacing boats and shields requires about four hours); changing and cleaning chamber side shields annually; and changing boat feed tips every third or fourth run. Rather than buying boat tips from the manufacturer, Titanium Finishing fabricates them on site.

2.2.3.6 Recordkeeping

Recordkeeping provides a database that can be used to diagnose problems, to form a basis for determining operating parameters for new parts, and to obtain repeatable results on parts routinely plated. Data related to each run should be maintained on file for use by the Ivadizer operators. Appendix A includes two forms used by Titanium Finishing for rack coating and barrel coating.

2.2.3.7 Cost-Effectiveness

Based on their commercial operations, Titanium Finishing reports that Ivadizer coatings on small iron and steel parts are two to four times more expensive than cadmium plating.[1] However, they also indicate that Ivadizer coatings are comparatively less costly when plating large parts.[1] If metals other than iron and steel are plated, an Ivadizer coating would be less costly than cadmium plating because no pretreatment is required while a preliminary nickel strike treatment would be required for cadmium plating. (Virtually all parts plated at ANAD are steel parts.)

SECTION 3

REGULATIONS AFFECTING CADMIUM-ELECTROPLATING OPERATION

The aluminum ion vapor coating process is impacted by few regulatory restrictions while cadmium electroplating is extensively regulated because cadmium is both toxic and a potential carcinogen. Regulation of cadmium and cadmium wastes has a significant impact on the cost of cadmium electroplating. Additional regulations are anticipated and will result in higher costs. This will make alternatives such as AIVD more cost competitive. Regulations impacting cadmium electroplating operations are summarized in this section to provide a basis for comparison with AIVD.

3.1 Water Quality Regulations

Table 3-1 lists the Federal Standards for effluents from cadmium electroplating operations.

TABLE 3-1. FEDERAL EFFLUENT LIMITS FOR CADMIUM ELECTROPLATING[a] (mg/L)

Description	Existing source	New source[b]
Cadmium effluent limit, 1-day maximum	0.69	0.11
Monthly average, not to exceed	0.26	0.07
Cyanide effluent limits, 1-day maximum	1.20	1.20
Monthly average, not to exceed	0.65	0.65

[a] Contained in 40 CFR, Part 433, Metal Finishing Point Source Category.
[b] Operations that began after August 31, 1982

Because of the restrictive discharge limits, the state-of-the-art technology for treating wastewaters from cadmium electroplating systems is a closed-loop system (Figure 3-1). In a typical closed-loop system, the electroplating solution is first rejuvenated by use of activated carbon to remove degraded organic brighteners and other organic agents. The solution is then refrigerated to precipitate sodium carbonate produced by the oxidation of sodium cyanide--a component of the solution. Solids are

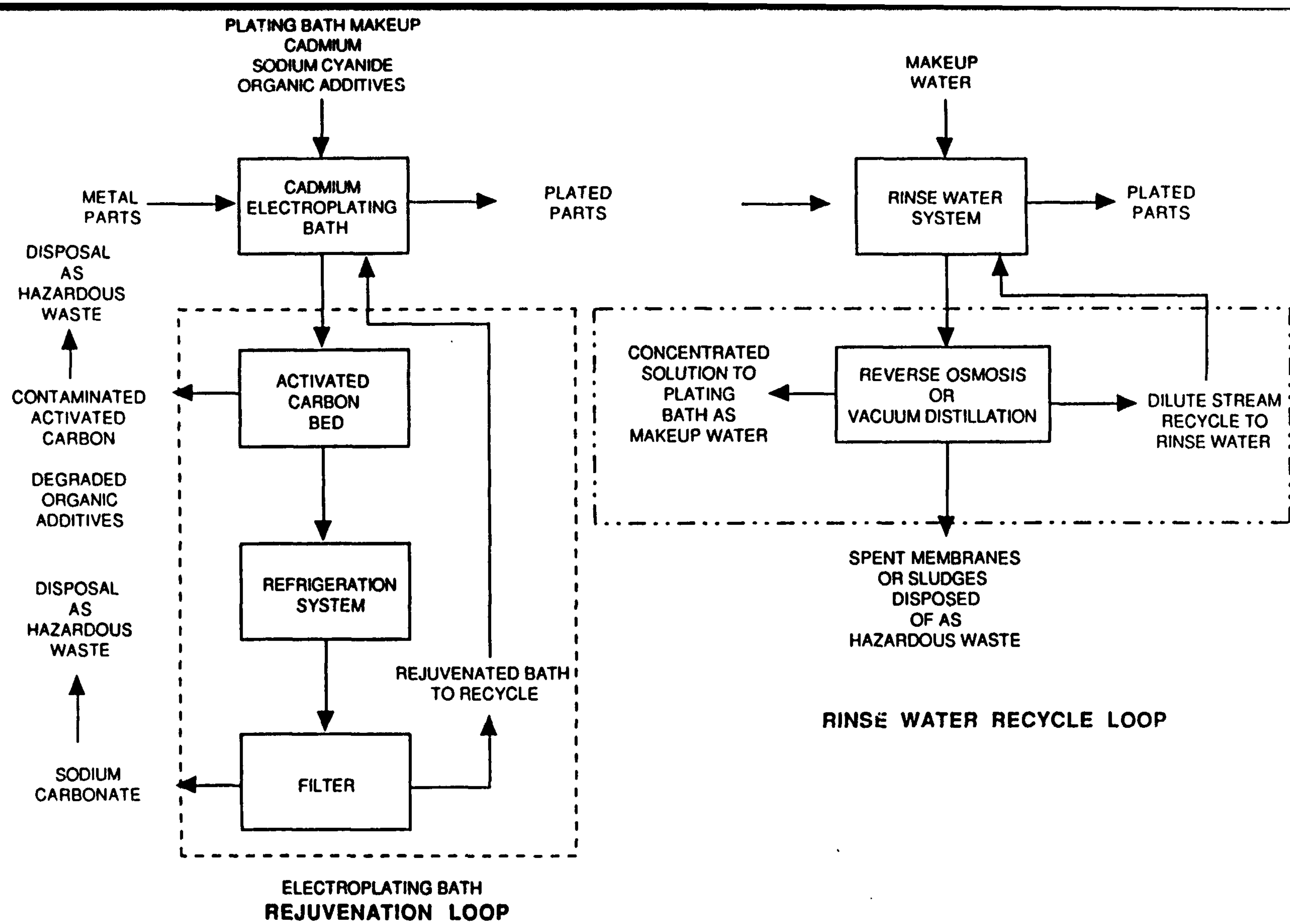

Figure 3-1. Schematic of a closed loop cadmium electroplating bath.

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removed by filtration. The solution is then returned to the plating tank, where cadmium, sodium cyanide, brighteners, and water are added as required. Spent activated carbon and precipitated sodium carbonate are disposed of as hazardous wastes.

The rinse water used during closed-loop operations is either vacuum distilled or treated by reverse osmosis (RO). Treated water is reused as rinse water, and the concentrated RO solution is used as plating bath makeup water. Vacuum distillation is necessary to avoid the loss of hydrogen cyanide when the rinse water is heated. Treatment sludges and debris (e.g., RO membranes) are disposed of as hazardous waste. A cadmium plating bath could be maintained indefinitely under such a system.

3.2 Occupational Exposure Standards

Table 3-2 lists applicable occupational exposure standards for cadmium. The Occupational Safety and Health Administration (OSHA) has determined that the current standard is not sufficiently protective and that employers have an obligation to reduce worker exposures to lower levels.[2] OSHA is currently preparing more stringent standards.

TABLE 3-2. APPLICABLE OCCUPATIONAL STANDARDS FOR CADMIUM

Description	Standard (mg/m^3)
Current OSHA standard	
Dust	0.2, never to exceed 0.6
Fume	0.1, never to exceed 0.3
ACGIH	
Current standard	
Dust and fume	0.05
Pending standard	
Total Dust	0.01
Respirable Dust (<10 μm)	0.002

In addition to lower exposure standards, other requirements will include medical monitoring, employee training, medical testing, and housekeeping requirements. These additional requirements will increase the cost of cadmium electroplating operations.

SECTION 4

COATING SPECIFICATIONS AND PERFORMANCE

Two specifications are applicable to the coatings being evaluated: 1) Federal Specification QQ-P-416E, Amendment 1, February 27, 1987, for electroplated cadmium (Appendix B); and 2) Military Specification MIL-C-83488C, July 30, 1987, for vapor-deposited aluminum (Appendix C). Both specifications identify three classes of coatings based upon coating thickness. Table 4-1 presents minimum coating thickness requirements.

TABLE 4-1. SUMMARY OF MINIMUM COATING THICKNESS REQUIREMENTS FOR CADMIUM ELECTROPLATES AND VAPOR-DEPOSITED ALUMINUM
(Coating thickness, mils)

	Cadmium		
Class	Area touched by 0.75-in. ball	Area not touched by 0.75-in. ball	Aluminum
1	0.50	0.30	1.00
2	0.30	0.20	0.50
3	0.20	0.15	0.30

The specifications require that corrosion protection be demonstrated by the coating's ability to withstand testing in a salt spray cabinet (Table 4-2). As indicated in the table, aluminum coatings provide substantially more protection. For example, Class 3 aluminum coatings provide more protection than Class 1 cadmium coating.

TABLE 4-2. CORROSION-RESISTANCE REQUIREMENTS OF CADMIUM AND ALUMINUM COATINGS
(Hours in salt spray booth)

	Cadmium		Aluminum	
Class	Without conversion coating[a]	With conversion coating	Without conversion coating	With conversion coating
1	96	168	504	672
2	96	168	336	504
3	96	168	167	336

[a] Conversion coating is a chromate coating that provides additional protection and a good base for painting.

Both specifications require visual inspection of coated parts and destructive testing of steel test coupons that have been simultaneously plated with actual parts. A cadmium electroplate on a part may appear satisfactory visually but provide insufficient protection. This can occur if the uniformity of the plating varies significantly as a result of the configuration of the part. Some areas may receive less-than-adequate plating but not be detected visually and ultimately may fail in service. A benefit of the AIVD process is that it virtually eliminates such false-positive visual test results. After the aluminum coat has been applied, peening with glass beads is used to densify the coating and provide a shiny metallic surface. Aluminum coatings that withstand this glass bead peening without flaking or peeling have passed a more stringent adhesion test than the visual test called for in the specifications. A poorly coated aluminum part is unlikely to pass the peening process and be put into field service.

Table 4-3 presents a comparison of the performance of cadmium electroplates and AVID aluminum coatings under various conditions.

TABLE 4-3. COMPARISONS OF SERVICE LIMITATIONS AND RESTRICTIONS FOR CADMIUM AND ALUMINUM COATINGS

Item	Cadmium electroplates	IVD aluminum coatings
Potential for hydrogen embrittlement of steel having a Rockwell C hardness of 40 or more	Requires 3 hours baking at 375 ± 25°F	No restrictions
Maximum surface temperature of coated parts	450°F	950°F
Use on titanium substrates	Restricted because of potential for solid metal embrittlement	No restrictions
Use on parts contacting fuel, food, or drinking water	Not allowed	No restrictions
Preload torque requirements for threaded fasteners	Standards are based on cadmium electroplates	Substantially more torque is required
Coated parts requiring soldering	Superior adherence of solder to coating	Restricted due to adherence of solder

SECTION 5

TORQUE REQUIREMENTS

Two reports by McDonnell-Douglas[3,4] document the fact that more torque is needed to achieve the same tension on aluminum-plated fasteners than on cadmium-plated fasteners. The difference is large enough that aluminum- and cadmium-coated fasteners cannot be used interchangeably. A discussion of the tolerances included in torque specifications, variations in torque required for identical fasteners, and differences between aluminum-plated and cadmium-plated fasteners is presented in this section.

5.1 Establishment of Torque Requirements

Torque requirements are set according to the following empirical equation developed by the Industrial Fasteners Institute:[5]

$$T = KDW$$

where

T = Torque in inch-pounds
K = 0.06 to 0.35 (cadmium - 0.17, steel - 0.20, zinc - 0.22, galvanized - 0.25)
D = Nominal bolt size in inches
W = Bolt tension in pounds where the target tension is 70 percent of the tensile strength, but can be lowered to 60 percent to provide a safety factor.[6]

Because of the many interrelated variables that directly or indirectly affect torque requirements, such as surface texture, type of coating or finish, lubrication, speed of tightening, and human error, as much as a ± 25 percent deviation in preload (clamp load) can be experienced with the use of a torque wrench.[6] A parts designer must consider this factor when setting torque and loading specifications.

5.2 Variations in Identical Fasteners

Boeing Aircraft made torque-tension measurements for 24 identical fasteners.[3] Twelve fasteners were coated with aluminum and 12 were coated with diffused nickel-cadmium (Table 5-1). (Although the current report deals with electroplated cadmium rather than diffused nickel cadmium, the diffused nickel cadmium data illustrate the scatter in torque for identical fasteners.) These data show the variability in measured tensions for the same applied torque.

TABLE 5-1. TORQUE-TENSION RELATIONSHIPS ON TWELVE IDENTICAL FASTENERS[a]

Torque (inch-pounds)	Tension			Range as percent of average
	Average	High	Low	
IVD Aluminum Fasteners				
80	1000	1262	815	44.7
111	1500	1780	1040	49.3
150	2000	2350	1650	35.0
187	2500	2880	2030	34.0
240	3100	3560	2480	34.8
275	3600	4120	2960	32.2
320	4100	4720	3460	30.7
352	4600	5400	3910	32.4
400	5240	6390	4390	38.2
437	5760	7070	4840	38.7
480	6430	8200	5410	43.4
				37.5 = Avg., 5.95% std. deviation
Diffused Nickel-Cadmium				
81	1000	1260	720	54.0
117	1500	1810	1240	38.0
156	2000	2330	1620	35.5
197	2500	2900	2020	35.2
240	3080	3590	2370	39.6
283	3640	4150	2990	31.9
320	4060	4480	3400	26.7
356	4600	5220	3980	27.0
400	5080	5900	4300	31.5
437	5660	7050	4740	40.8
480	6350	7890	5430	38.7
				36.3 = Avg., 7.59% std. deviation

[a] Source: Reference 3. Tensile strength of fasteners is 14,100 pounds.

McDonnell-Douglas also tested different nut and bolt combinations, and measured loading as a function of torque (Table 5-2). These data also show the variability in the torque-tension relationship. In one test, the torques required to produce a 20,000-pound loading were measured for 17 new half-inch aluminum-coated nuts and bolts that were lubricated with synthetic graphite in petrolatum. The average torque was 811 inch-pounds with a range of 700 to 950 inch-pounds. Torque measurements were also made for 14 other assemblies: seven had aluminum-coated bolts and cadmium-plated nuts; the other seven had both cadmium-plated nuts and bolts. Torque requirements for these two groups ranged from 575 to 720 inch-pounds.

5.3 Variations Between Aluminum-Coated and Cadmium-Electroplated Fasteners

Table 5-2 presents data that compares torque requirements for 17 Ivadized aluminum-plated and cadmium-electroplated nut and bolt combinations. The average torque required to produce a 20,000-pound load was 35 percent higher for aluminum than for the combinations of cadmium-plated fasteners. The average torque for the cadmium-plated combinations was 600 inch-pounds while the average for the aluminum-plated fasteners was 811 inch-pounds.

Tests B through E reported in Table 5-2 involved smaller numbers of samples: three aluminum fasteners and six cadmium fasteners each. On average, 15 percent more torque was required to achieve the same tension in aluminum fasteners as compared to cadmium-plated units.

The results of these tests indicate that AIVD aluminum cannot be substituted for cadmium as a fastener coating without revising torque requirements, plating procedures, lubrication practice, or some combination of all three.

5.4 Variations Over Multiple Installation/Removal Cycles

The torque required to achieve a given load should not vary significantly over 15 cycles of installation and removal (defined as the designed work-life of a nut and bolt combination) if loading is determined by an applied torque requirement. Table

TABLE 5-2. TORQUE-LOADING COMPARISONS FOR IDENTICAL ALUMINUM- AND CADMIUM-PLATED FASTENERS[a]

	Aluminum-coated nut and bolt			Cadmium-coated nut, aluminum-coated bolt			Cadmium-plated nut and bolt			
Test	No. of tests	Avg. torque, inch-pounds	Range of torques, inch-pounds	No. of tests	Avg. torque, inch-pounds	Range of torques, inch-pounds	No. of tests	Avg. torque, inch-pounds	Range of torques, inch-pounds	Torque ratio Al/Cd
A	17[b]	811	700 to 950	7	629	575 to 675	7	600	580 to 720	1.35
B	3[c]	1861	1714 to 1935	3	1561	1519 to 1627	3	1549	1406 to 1704	1.20
C	3[d]	1299	1134 to 1527	3	825	757 to 877	3	919	855 to 972	1.41
D	3[e]	1553	1447 to 1677	3	1365	1349 to 1377	3	1413	1316 to 1511	1.10
E	3[f]	211	138 to 253	3	221	198 to 245	3	234	223 to 248	0.90

[a] Source: Reference 3.

[b] Bolt has 0.4987-inch shank diameter; lubricant was 50% synthetic graphite in petrolatum; all loadings were 20,000 lb.

[c] Bolt has 0.7483-inch shank diameter; lubricant was 50% synthetic graphite in petrolatum; loadings were 30,000 lb.

[d] Bolt has 0.6237-inch shank diameter; lubricant was 50% synthetic graphite in petrolatum; loadings were 20,000 lb.

[e] Bolt has 0.5610-inch shank diameter; lubricant was 50% synthetic graphite in petrolatum; loadings were 30,000 lb.

[f] Bolt has 0.3110-inch shank diameter; lubricant was 50% synthetic graphite in petrolatum; loadings were 8,000 lb.

5-3 presents data for 17 aluminum-coated nut and bolt combinations, 7 combinations with an aluminum-coated bolt and a cadmium-plated nut, and 7 combinations with a cadmium-plated nut and bolt. The table lists the torque required to achieve a 20,000-pound load for each of the 15 cycles.[3]

TABLE 5-3. TORQUE REQUIREMENTS THROUGH FIFTEEN CYCLES OF INSTALLATION AND REMOVAL[a]

(Units are in inch-pounds required to apply a 20,000-pound tension)

Cycle No.	Aluminum nut and bolt	Cadmium nut and aluminum bolt	Cadmium nut and cadmium bolt
1	811 ± 67	629 ± 41	660 ± 44
2	807 ± 39	671 ± 83	661 ± 23
3	778 ± 44	672 ± 89	660 ± 37
4	766 ± 46	674 ± 95	651 ± 43
5	759 ± 53	685 ± 78	648 ± 40
6	744 ± 53	673 ± 68	644 ± 32
7	730 ± 48	658 ± 56	651 ± 38
8	723 ± 48	651 ± 43	651 ± 38
9	717 ± 46	654 ± 34	648 ± 40
10	719 ± 39	661 ± 32	656 ± 30
11	724 ± 64	657 ± 19	644 ± 38
12	702 ± 41	661 ± 20	649 ± 31
13	699 ± 36	664 ± 24	637 ± 37
14	686 ± 35	661 ± 20	646 ± 36
15	704 ± 37	675 ± 25	661 ± 23

[a] Source: Reference 3.

The difference in torque requirements for the cadmium nut and bolt combinations and the cadmium nut and aluminum bolt combination is within a standard deviation, and the two combinations could be used interchangeably.[3] For these two combinations, torque requirements do not significantly change over 15 installation/removal cycles.

The initial torque requirement for the aluminum nut and bolt combination was about 25 percent higher than those of the cadmium-plated units. After 15 cycles, the torque requirement was only about 6 percent higher. The reason for this decrease was not identified, nor did the report address whether the aluminum coating was still providing adequate corrosion protection after 15 cycles.[3]

5.5 Reduction of Torque Differences

The Pensacola Naval Air Station applies AIVD aluminum coatings on fasteners that are used on helicopter rotor heads. Torque differences between these aluminum-plated parts and the specified cadmium-plated parts are minimized by using a thin coating (0.3 mil, Class 3 aluminum coating), by peening the coating with glass beads, and by using a cetyl alcohol lubricant. Torque is applied and checked 4 to 6 hours later. The AIVD coating is applied at a slower than usual rate (25 percent wire feed rather than 35 percent wire feed) to minimize variations in plating. Although more than normal effort and attention is required during plating and assembly, torque differences are kept at acceptable levels by these operational practices.

McDonnell-Douglas tested a very thin AIVD coating (0.15 to 0.17 mil) on five nut and bolt combinations.[4] (The minimum thickness is 0.3 mil for a Class 3 coating.) Torque requirements for these thin coatings were lower than for normal AIVD coatings, but were still greater than those required for electroplated cadmium fasteners. The test results indicated that torque requirements for the thin AIVD coatings could not be confidently maintained within the ±25 percent range specified for the cadmium electroplates.

A 50 percent synthetic graphite in petrolatum lubricant was used during almost all of the McDonnell-Douglas tests involving both aluminum and cadmium fasteners. Additional investigations indicated that solid dry film lubricants, which incorporate either molybdenum disulfide or graphite in a resin binder, could bring torque requirements for AIVD coatings to within the range of cadmium-plated fasteners.

SECTION 6

DEMONSTRATION TESTS AT ANAD

Demonstration tests of a full-scale Ivadizer system were conducted at ANAD between October 1990 and April 1991. (Appendix D provides an overview of the Test Plan.) The primary objective of the demonstration test was to determine if the Ivadizer is a viable alternative to cadmium electroplating at ANAD. A secondary objective was to develop the operating skills of ANAD's Ivadizer operators. Additionally the tests were used to establish operating parameters such as wire feed rate and boat speed in order to achieve reproducible coatings that satisfy specifications regarding coating thickness, adherence, corrosion protection, and appearance.

6.1 Test Results

The AIVD Demonstration Test Program conducted by USATHAMA at Anniston Army Depot provided the following results:

- ANAD personnel could satisfactorily coat all parts tested.
- Aluminum coatings provided at least equivalent corrosion protection compared with cadmium electroplates.
- Aluminum coatings had satisfactory adherence to the base metal.
- Torsion testing of threaded fasteners demonstrated that aluminum-coated fasteners required substantially greater applied torque than did equivalent cadmium-coated fasteners.
- Based on the test, ANAD personnel have recommended Ivadizer coatings as an optional coating for Model 1790 engine components.

Eighty-six parts used on Army vehicles and engines were successfully plated in the Ivadizer. Additionally, numerous nuts, bolts, brackets, and other small parts were successfully plated using a barrel coater. On a few occasions, applied coatings did not meet thickness specifications. Operating conditions and methods were changed in order to achieve compliance. These changes included extending plating times and plating in two stages, with rotation between stages. Appendix E presents a detailed summary of test conditions and results.

The Military Specification for Aluminum Ion Vapor Deposition Coatings differentiates between Type I coatings that are as-is and Type II coatings that receive a chromate conversion coating. The Ivadizer operating procedures are identical for Type I and Type II coatings, and a satisfactory chromate conversion coating was routinely applied to aluminum coatings. Therefore, Type I and Type II coatings are similar with the exception of salt spray corrosion resistance requirements.

Five aluminum-coated parts were tested in the salt spray cabinet; satisfactory results were obtained on four of the five parts. The fifth part (Part No. 11683952, Connector, Male) had a hollow male connection at a 45-degree angle to the base. Corrosion was detected inside the connection. The interior of the connection apparently received better coating when the hollow was positioned perpendicular to the plating boats.

The specification for salt spray corrosion testing states that the appearance of white corrosion products on the aluminum coating during the test period is not cause for rejection. This direction differs from the specification for cadmium plating. White corrosion products may appear on AIVD coatings because aluminum is both a protective and a sacrificial coating. The aluminum corrosion product is aluminum oxide, a white material, and indicates that the aluminum coating has performed its function.

6.2 Test Coupons

The Military Specifications require that test coupons be used to monitor both aluminum- and cadmium-plating operations. A test coupon is a thin metal sheet that can be tested in lieu of the actual parts either when destructive testing is required or when the parts cannot be tested as a result of shape or size. Typical test coupons are mild steel sheets 4-in.-by-1-in. and 0.040-in.-thick or 6-in.-by-3-in. and 0.040-in.-thick. Because the coupons are flat and not have sharp angles, cavities, or recessed areas, they are easier to plate with minimum variations in thickness than are actual parts. Therefore, thickness measurements were made, whenever possible, on the actual parts.

Scrap parts and test coupons were tested in the salt spray cabinet, and all items tested, with the exception of the male connector mentioned previously, passed both adhesion and corrosion resistance testing. The results of salt spray cabinet testing are included in Appendix E.

SECTION 7

DISCUSSION

7.1 Cadmium and Cyanide in ANAD's Electroplating Facility

The following data were used to estimate quantities of cadmium and cyanide involved in cadmium electroplating at ANAD.

- A description of the cadmium electroplating facility at ANAD compiled during several visits to the depot
- Estimated amounts of cadmium and cyanide in the system, and their annual consumption
- Reported quantities of hazardous waste generated from cadmium electroplating
- Amount of plating shop wastewater processed in ANAD's industrial wastewater treatment plant (IWTP)

Figure 7-1 is a schematic showing cadmium and cyanide balances around ANAD's plating lines. Table 7-1 presents cadmium and cyanide usage data for 1990. The data are based upon ANAD's estimated production rate and an average coating thickness of 0.5 mil (0.0005 inch).

TABLE 7-1. CADMIUM AND CYANIDE USAGE AT ANAD IN 1990

Parameter	Usage
Capacity of plating lines	6,140 gal
Concentration of cadmium	4 oz/gal of solution (typical)
Concentration of cyanide	20 oz/gal of solution (typical)
Cadmium/line	1,500 lb
Cyanide/line	7,700 lb
Additions of cadmium	2,500 lb
Additions of cyanide	1,600 lb
Cadmium to product	1,700 lb
Cadmium to waste sludge and wastewater	800 lb
Cyanide waste	1,500 lb
Cyanide air losses	100 lb
Wastewater	250,000 gal/yr

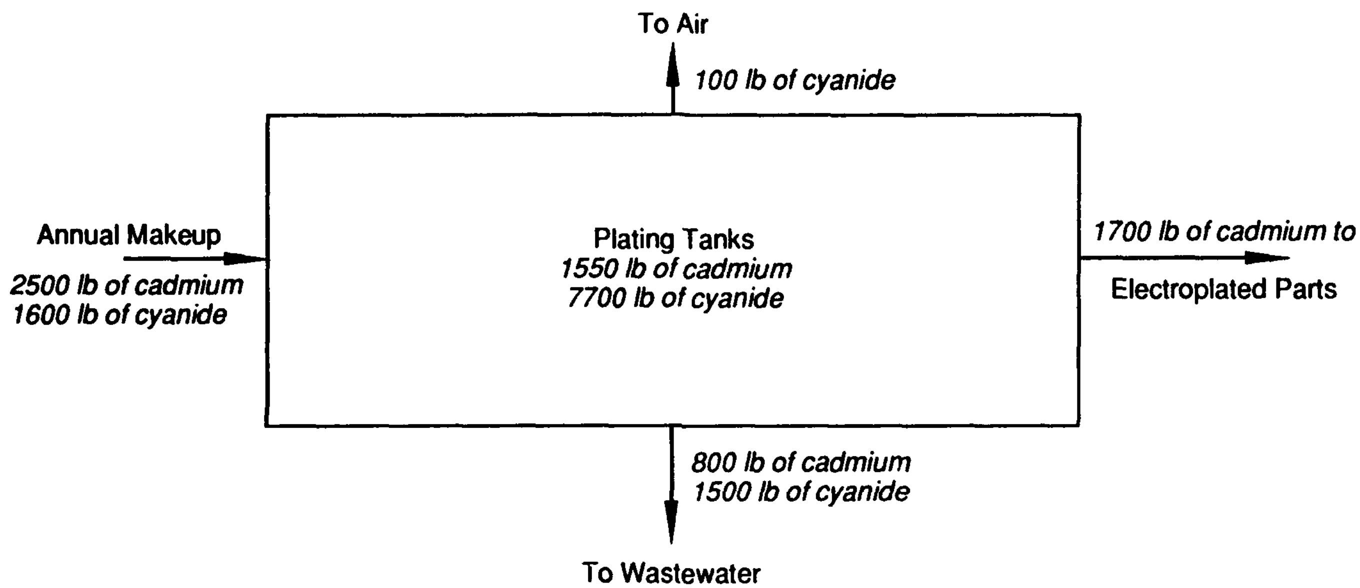

Figure 7-1. Cadmium and cyanide balance in ANAD's Cadmium-Plating Operations.

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Use of Ivadizer technology could eliminate the rinsewater stream (250,000 gallons per year) and the cadmium plating tank wastes. The stripping tanks would continue to be a source of cadmium waste, however, because cadmium-plated parts currently in field service would continue to be stripped prior to plating. Although this waste source will continue whether the Ivadizer is used or cadmium plating is continued, it eventually would be eliminated if the Ivadizer completely replaces cadmium electroplating.

7.2 Waste Disposal Costs Attributable to Cadmium Electroplating

Cadmium electroplating operations generate the following Resource Conservation and Recovery Act (RCRA) listed hazardous wastes as defined in 40 CFR Part 261:

- F006 - Wastewater treatment sludges from electroplating operations
- F007 - Spent cyanide plating bath solutions from electroplating operations
- F008 - Plating sludges from the bottom of plating baths from electroplating operations where cyanides are used in the process
- F009 - Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process

In 1990, ANAD reported that 14,677 pounds of hazardous waste was generated by cadmium electroplating operations. A breakdown by specific waste types was not available.

Costs in 1990 were $7,340 for hazardous waste disposal ($0.50 per pound) and $91,250 for wastewater treatment in ANAD's IWTP ($0.365 per gallon) for a total waste disposal cost of $98,590. More stringent regulatory standards would increase the cost of compliance or could render compliance unachievable with the current operational configuration and waste treatment/disposal system.

7.3 Medical Monitoring Costs Attributable to Cadmium Electroplating

The expected reduction of the OSHA standard for employee exposure to cadmium (Table 3-2) will generate additional costs resulting from more stringent employee and area monitoring requirements. These costs can be estimated by analogy with OSHA requirements for lead exposures as set forth in 29 CFR 1910.125.

The estimated increased annual cost is $15,400 as shown in Table 7-2. This cost estimate is believed to represent minimum costs because cadmium is classified as both toxic and carcinogenic while lead is classified as toxic.

TABLE 7-2. ESTIMATED ADDITIONAL COSTS ASSOCIATED WITH MORE STRINGENT EMPLOYEE MEDICAL AND EXPOSURE REQUIREMENTS ATTRIBUTABLE TO CADMIUM ELECTROPLATING

	Annual cost
Quarterly monitoring costs	
One day per quarter of on-site monitoring at $600	2,400
One day per quarter for sample handling and report writing at $600	2,400
Eight cadmium analyses per quarter at $50 each	1,600
Semiannual blood tests	
30 tests every 6 months at $50 (includes sample taking)	3,000
Increased cost of annual employee physical examinations	
30 examinations at $200 each	6,000
Total Additional Cost	$15,400

7.4 Cost of Aluminum and Cadmium Coatings

7.4.1 Capital Cost

Table 7-3 presents installed capital costs of an Ivadizer and a cadmium electroplating facility. Estimated capital costs are $1,025,000 for the Ivadizer system and $600,000 for the cadmium-plating facility. These capital cost estimates do not include degreasing, cleaning, stripping, and rinsing facilities that are common to both systems. The Ivadizer cost estimate is based upon the actual costs incurred during this project for installation of the system at ANAD. The cadmium-plating cost estimate is based upon estimates from vendors for a facility equivalent to that currently in place at ANAD.

TABLE 7-3. CAPITAL COST COMPARISONS BETWEEN ALUMINUM COATING AND CADMIUM ELECTROPLATING

Item	Cost
AIVD	
Ivadizer Model HR72X144	$437,500[a]
Two additional parts coating racks	57,600[a]
Barrel coating parts rack	28,500[a]
Two grit blasting cabinets	77,000[a]
Cryogenic cooling system	35,000[a]
Two glass bead peening cabinets	77,000[a]
Recommended spare parts	40,900[a]
Manufacturer's installation and training	92,200[a]
Customer-supplied facility modification and freight	179,300[b]
TOTAL CAPITAL COST	$1,025,000
Cadmium Electroplating	
1100-gal. automatic cadmium-electroplating system	$310,000[c]
Two 1800-gal. cadmium-plating lines	100,000[c]
Three 480-gal. cadmium-plating lines	60,000[c]
Customer-supplied facility modifications and freight	130,000[b]
TOTAL CAPITAL COST	$600,000

[a] Actual price of AVID system installed at ANAD.

[b] Estimate by ANAD and IT staff.

[c] Vendor quote.

The estimated cost of the cadmium plating facility is based upon current regulations. More stringent regulatory requirements would, at best, significantly increase capital costs and, at worst, render cadmium plating infeasible. For example, state regulations have eliminated most cadmium electroplating at Red River Army Depot and at Jacksonville Naval Air Station. Present regulatory requirements coupled with the prospect of more stringent future requirements would probably make an Ivadizer the preferred choice over cadmium electroplating for a new facility. The choice facing most Army installations, however, is whether to replace an existing cadmium plating facility with an Ivadizer. In this case, a reasonable assumption would be that the cadmium plating facility can be converted to another use at its present depreciated value.

Retrofitting a cadmium plating facility to achieve zero discharge standards would be expensive, and the cost would be very situation-specific. For a facility the size of ANAD, the cost would be between $300,000 and $400,000. This estimate is based on the purchase of two vacuum evaporators at $60,000 to $70,000 each and an installation cost at least equal to equipment cost. The feed for the evaporators would be supplied by the second-stage rinse tanks. System design and engineering would be a significant effort and expense. A new zero discharge cadmium-plating facility would cost almost as much as an Ivadizer system.

7.4.2 Annual Costs

The cadmium-plating facility at ANAD can plate about 490 ft^2 of metal surface per 8-hour shift (61 baskets of parts at 8 ft^2 per basket) with a normal production rate of about 320 ft^2 per shift (40 baskets at 8 ft^2 per basket). The Ivadizer as now installed has a capacity of about 144 ft^2 per shift. It is estimated that about $100,000 of equipment modifications could increase this rate to about 200 to 250 ft^2 per shift. (These modifications are included in the capital cost estimate). An Ivadizer in a commercial job shop environment can coat about 270 feet of metal surface in an 8-hour shift.

Table 7-4 presents estimated annual costs of an Ivadizer system and a cadmium-electroplating facility. Estimated annual costs per square foot plated are $6.64

for aluminum and $4.47 for cadmium. (These costs do not include degreasing, cleaning, stripping, and rinsing facilities that are common to both the Ivadizer and cadmium plating.) In each case, it was assumed that 76,160 ft^2 is plated per year. The Ivadizer would operate 2 shifts per day to achieve this production rate.

ANAD's cadmium-plating facility has an advantage in that the wastewater generated can be treated in the depot's IWTP. A zero discharge system would have higher capital and operating costs. Table 7-4 shows that about one-third of the annual costs for cadmium plating are attributable to hazardous waste treatment and disposal and employee protection. These costs will increase whenever more stringent standards are imposed. Such developments could reduce or eliminate the cost differential between aluminum plating and cadmium plating.

7.4.3 Ivadizer Coatings in Field Service

Navy and Air Force facilities have used Ivadizers for about three years. Operating experience demonstrates that aluminum coatings outlast cadmium coatings in field service. Personnel at Pensacola Naval Air Station report that Ivadizer coatings held up much better than cadmium electroplates on aircraft used in the Persian Gulf campaign. Landing gear parts and rod end covers on military aircraft and steel wing hinge fittings on commercial aircraft are aluminum coated and have provided good service.[3,4]

7.5 Summary of Findings

The results of this evaluation indicate that Ivadizer-applied aluminum coatings are equal or superior to and can replace cadmium coatings on parts tested. Replacement of cadmium electroplating with the Ivadizer technology will significantly reduce generation of cadmium-contaminated wastes at ANAD. In most cases, Ivadizer technology could be substituted directly for cadmium electroplating and would require minimal changes in pretreatment or posttreatment procedures. Pretreatment of parts with welded surfaces and recessed areas may require modification to include preheating to eliminate outgassing from trapped moisture. Posttreatment changes would include lubrication of Ivadized threaded parts prior to assembly as well as

TABLE 7-4. ANNUAL COST COMPARISONS BETWEEN ALUMINUM COATING AND CADMIUM ELECTROPLATING

Annual Costs of the Ivadizer	
Day shift labor, 3 people, \$20/h, 2080 h/year	124,800
Night shift labor, 3 people, \$22/h, 2080 h/year	137,280
Maintenance, 2% of capital cost	20,500
Utilities, \$10/h, 3800 h/year	38,000
Wire, \$6.50/h, 3800 h/year	24,700
Boats, \$9/h, 3800 h/year	34,200
Capital recovery, 9%, 15 years	125,850
Total Annual Cost	505,330
Cost plated, \$/ft^2	6.64
Annual Costs of Cadmium Plating	
Day shift labor, 3 people, \$20/h, 2080 h/year	124,800
Maintenance, 2% of capital cost	12,000
Utilities, \$1/h, 1900 h/year	1,900
Cadmium metal, \$5.015/lb, 2500 lb/year	12,540
Sodium cyanide, \$1.15/lb, 1600 lb/year	1,840
Capital recovery, 9%, 15 years	73,670
Hazardous waste disposal, 14,700 lb at \$0.50/lb	7,350
Wastewater treatment, 250,000 gal/year at \$0.365/gal	91,250
Employee cadmium exposure monitoring	6,400
Blood tests for cadmium	3,000
Increment annual physical exam costs	6,000
Total Annual Costs	340,750
Cost plated, \$/ft^2	4.47

separation from cadmium-plated fasteners, particularly for parts with critical torque requirements.

Additionally, parts with recesses more than one diameter deep (two diameters deep if open at both ends) and where the interior must be coated will require another coating technique for the interior as the Ivadizer cannot coat these recesses. Three classes of alternative coatings are:

- Aluminum-filled MIL-C-81517 base coats
- Ceramic sealcoats
- Primers, topcoats, and sealants

The aluminum-filled base coats are paint-type materials that contain suspended aluminum metal. The aluminum-filled coating becomes electrically conductive when either heat-cured or burnished with glass beads. The aluminum coating then provides sacrificial corrosion resistance. The ceramic sealcoat is a painted-on protective coating that is usually heat-cured. It forms a solid film and is often used on top of aluminum-filled base coats. Primers, topcoats, and sealants provide solid film protective coatings. Materials used include epoxies, polyurethanes, and sprayable sealants.

As a result of demonstration tests, ANAD personnel have proposed that Ivadizer coatings be made an acceptable alternative to cadmium electroplates. The substitution requires the approval of the Army Tank Automotive Command. Depot personnel have identified about 450 vehicle and engine parts that are suitable for aluminum coatings in place of cadmium electroplates (Appendix F).

Total replacement of cadmium electroplating by aluminum vapor deposition would eliminate the generation of about 15,000 pounds of RCRA-listed hazardous wastes and 250,000 gallons of wastewater annually. However, the current cost of Ivadizer coatings is estimated to be about 50 percent greater than cadmium electroplates. The cost of operating cadmium-plating lines will continue to increase because of increasingly more stringent regulations, while the cost of Ivadizer coatings should decrease as the technology matures.

SECTION 8

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8. Anniston Army Depot, Anniston, Alabama, ANAD Process Control Pamphlet, Cadmium Plating, p. 13.

APPENDIX A

FORMS USED BY TITANIUM FINISHING

RACK COATING

Part Number ______________________

Part Description ______________________

Coating Thickness ______________________

Glow Disc. Time/Voltage ______________________

Max. Substrate Temp °F ______________________ Material ______________________

Cooling Cycle Frequency ______________________ Durantion ______________________

Coating Cycle:

	Pass	Wire Feed	Boat Speed	Rack Speed
Side 1				
	1			
	2			
	3			
	4			
Side 2				
	1			
	2			
	3			
	4			

Part Locations - See Chart

Figure A-1. Titanium Finishing's rack coating operating log.

Figure A-1. (continued)

SIDE ____

- PUMP DOWN #1
- GLOW DISCHAR.
- COOL DOWN

- PUMP DOWN #2
- GLOW DISCHAR.
- PREHEAT
- RUN
- COOL DOWN

- PUMP DOWN #3
- GLOW DISCHAR.
- PREHEAT
- RUN
- COOL DOWN

- PUMP DOWN #4
- GLOW DISCHAR.
- PREHEAT
- RUN
- COOL DOWN

- PUMP DOWN #5
- GLOW DISCHAR.
- PREHEAT
- RUN
- COOL DOWN

- RUN COMPLETE

Grid rows: 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Grid columns: 1 2 3 4 5 6 7 8 9 10 11 12 13 14

DATE: ____
RACK NO.: ____
NO. OF PASSES: ____
WIRE FEED RATE: ____
RACK SPEED: ____
COATING PRESSURE: ____
CLASS: ____
B/BREAK & INSP.: ____
MATERIAL TYPE: ____
TIME: ____
SHIFT: ____
PASS NO.: ____
SIDE COATED: ____
(1ST OR 2ND) ____

PARTS THAT FAILED PEENING

LEFT FRONT RIGHT

1 2 3 4 5 6 7 BOAT POSITION AND NUMBER

BARREL COATING

Part Number ________________

Part Description ________________

Max. Pieces/Barrel (wt/vol) ________________

Coating Thickness ________________

Glow Cycle ________________

Part Temperature Restrictions (°F) ________________

Cooling Cycle ________________

History W/O #	History Date	Pieces Barrel #1	Pieces Barrel #2	Boat Location (Seconds @ % Set)	Barrel Speed Setting	Wire Feed Setting	Coating Time

Figure A-2. Titanium Finishing's barrel plating operating log.

Figure A-2. (continued)

Part Number ______________________________

Part Description __________________________

28														
27														
26														
25														
24														
23														
22														
21														
20														
19														
18														
17														
16														
15														
14														
13														
12														
11														
10														
9														
8														
7														
6														
5														
4														
3														
2														
1														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14

APPENDIX B

FEDERAL SPECIFICATION QQ-P-416E
PLATING, CADMIUM (ELECTRODEPOSITED)

QQ-P-416E
AMENDMENT 1
27 FEBRUARY 1987

FEDERAL SPECIFICATION

PLATING, CADMIUM (ELECTRODEPOSITED)

This amendment, which forms a part of QQ-P-416E, dated December 18, 1982, is approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

PAGE 1
Paragraph 1.1: Delete the second sentence.

PAGE 14
Paragraph 6.2.3: Delete Entire Paragraph
Paragraph 6.2.4: Delete Entire Paragraph

MILITARY INTEREST:

Custodians

Army - MR
Navy - AS
Air Force - 20

Review Activities
Army - AL, AR, ER
Navy - EC, OS
Air Force - 70, 99
DLA - IS(E)

User Activities
Army - AT, ME, MI
Navy - MC, YD

CIVIL AGENCY COORDINATING ACTIVITIES:

GSA - FSS
COM - NBS

Preparing Activity
NAVY - AS
Project No. MFFP-0362

AMSC N/A

AREA MFFP

DISTRIBUTION STATEMENT A, Approved for public release; distribution is unlimited.

QQ-P-416E
18 April 1986
SUPERSEDING
QQ-P-416D
20 November 1985

FEDERAL SPECIFICATION

PLATING, CADMIUM (ELECTRODEPOSITED)

This specification is approved by the Commissioner, Federal Supply Service, General Services Adminstration, for use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers the requirements for electrodeposited cadmium plating. Any process of cadmium deposition should not be used when an alternate process meets the performance requirements of this specification and is considered satisfactory for use on the item under consideration (See 6.2.4).

1.2 Classification.

1.2.1 Classes. Cadmium plating shall be of the following classes, as specified (see 6.2):

Class 1 - 0.00050 inch thick.
Class 2 - .00030 inch thick.
Class 3 - .00020 inch thick.

1.2.2 Types. Cadmium Plating shall be of the following types, as specified (see 6.2):

Type I - As plated.
Type II - With supplementary chromate treatment (see 3.2.9)
Type III - With supplementary phosphate treatment (see 3.2.10)

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

AREA MFFP

AMSC N/A

DISTRIBUTION STATEMENT A, Approved for public release; distribution is unlimited.

Federal Specifications:

QQ-S-624 - Steel Bar, Alloy, Hot Rolled and Cold Finished (General Purpose).
TT-C-490 - Cleaning Methods and Pretreatment of Ferrous Surfaces for Organic Coatings.

Federal Standard

Fed. Test Method Std. No. 151 - Metals; Test Methods.

(Activities outside the Federal Government may obtain copies of Federal Specifications and Standards as outlined under General Information in the Index of Federal Specifications and Standards and at the prices indicated in the Index. The Index, which includes cumulative monthly supplements as issued, is for sale on a subscription basis by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

(Single copies of this specification and other Federal Specifications required by activities outside the Federal Government for bidding purposes are available without charge from Business Service Centers at the General Services Administration Regional Offices in Boston, New York, Washington, D.C., Atlanta, Chicago, Kansas City, Mo., Fort Worth, Denver, San Francisco, Los Angeles, and Seattle, WA.

(Federal Government activities may obtain copies of Federal Specifications and Standards and the Index of Federal Specifications and Standards from established distribution points in their agencies.)

Military Specification:

MIL-S-5002 - Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems

Military Standards:

MIL-STD-105 - Sampling Procedures and Tables for Inspection by Attributes.

MIL-STD-1312 - Fasteners, Test Methods.

(Copies of Military Specifications and Standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials (ASTM) Standards:

B117 - Salt Spray (Fog) Testing
B487 - Measuring Metal and Oxide Coating Thickness by Microscopic Examination
B499 - Measuring Coating Thickness by Magnetic Method-Nonmagnetic Coatings on Magnetic Basis Metal
B504 - Measurement of the Thickness of Metallic Coatings by the Coulometric Method
B529 - Measurement of Coating Thickness by the Eddy Current Test Method; Nonconductive Coatings on Nonmagnetic Basis Metals
B567 - Test for Measuring Coating Thickness by the Beta-Back-scatter Principle"
B568 - Test for Measuring Coating Thickness by X-Ray Spectrometry
E8 - Tension Testing of Metallic Materials

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103).

3. REQUIREMENTS

3.1 Materials. The materials used shall be such as to produce platings which meet the requirements of this specification.

3.2 General requirements.

3.2.1 High tensile strength steel parts. Unless otherwise specified, steel parts having an ultimate tensile strength greater than 240,000 pounds per square inch (psi) shall not be plated without specific approval of the procuring activity (see 6.2).

3.2.2 Stress relief treatment. Unless otherwise specified, all steel parts having an ultimate tensile strength of 150,000 pounds per square inch (psi) and above, which are machined, ground, cold formed or cold straightened, after heat treatment, shall be baked at a minimum of 375 ± 25°F (191 ± 14°C) for three hours or more prior to cleaning and plating for the relief of damaging residual tensile stresses (see 6.2).

3.2.3 Cleaning. Unless otherwise specified, all steel parts shall be cleaned in accordance with MIL-S-5002 (see 6.2).

3.2.4 Plating application. Unless otherwise specified, the plating shall be applied after all basis metal heat treatments and mechanical operations, such as machining, brazing, welding, forming and perforating of the article have been completed (see 6.2).

3.2.5 Underplating. Unless otherwise specified, cadmium shall be deposited directly on the basis metal without a preliminary plating of other metal, such as nickel, or copper, except in the case of parts made of corrosion-resistant alloys on which a preliminary plating of nickel is permissible or of parts made of aluminum on which a preliminary treatment such as the zincate process is permissible (see 6.2).

3.2.6 Coverage. Unless otherwise specified, the plating shall cover all surfaces as stated in 3.3.1, 3.3.1.1 and 3.3.1.2 including roots of threads, corners and recesses (see 6.2).

3.2.7 Luster. Unless otherwise specified, either a bright or dull luster shall be acceptable (see 6.2). However, parts for aircraft and aerospace applications, that are heat treated to Rockwell C40 and above, shall have a dull luster or finish.

3.2.8 Embrittlement relief. Unless otherwise specified or stated in the end product specifications, all steel parts having a hardness of Rockwell C40 and higher shall be baked at a minimum of 375 ± 25°F (191 ± 14°C) for three hours or more, within four hours after plating, to provide hydrogen embrittlement relief (see 6.6). The baked parts, when tested in accordance with 4.5.4, shall not crack or fail by fracture (see 4.4.3.4). Plated springs and other parts subject to flexure shall not be flexed prior to hydrogen embrittlement relief treatment. In the case of types II and III treated parts, the baking treatment shall be done prior to the application of the supplementary coatings. Cadmium plated surfaces passivated as a result of the baking operation shall be reactivated prior to receiving the type II supplementary chromate treatment (see 6.9).

3.2.9 Chromate treatment (Type II). Unless otherwise specified in the contract or order (see 6.2), the chromate treatment required for conversion to Type II shall be a treatment in or with an aqueous solution of salts, acids, or both, to produce a continuous smooth, distinct protective film, distinctly colored iridescent bronze to brown including olive drab and yellow. The articles so treated shall be thoroughly rinsed and dried in accordance with the requirements of the process used. Type II plating shall be similar in appearance to platings on separate specimens which are capable of passing the salt-spray test (see 3.3.4, 4.4.3.3, and 4.5.3). Usual chromic and nitric acid bright dips for cadmium are not chromate treatments.

3.2.10 Phosphate treatment (Type III). Unless otherwise specified in contract or order the phosphate treatment required for conversion to type III shall produce a tightly adherent film conforming to type I of TT-C-490 (see 6.2).

3.3 Detail requirements.

3.3.1 Thickness of plating. Unless otherwise specified in the contract or order, (see 6.2), the thickness of cadmium for other than fastener hardware (see 3.3.1.1) shall be as specified in Table I on all visible surfaces which can be touched by a ball 0.75 inch in diameter. Where Class 1 is specified, all other visible surfaces shall be Class 2 minimum thickness. If the maximum thickness for Class 1 is not specified in the contract, order or applicable drawing, the thickness shall not exceed 0.0008 inch (0.8 mil). Where Class 2 is specified, all other visible surfaces shall be Class 3 minimum thickness. Where Class 3 is specified, all other visible surfaces shall be not less than 0.00015 inch minimum thickness.

3.3.1.1 For fastener hardware. Unless otherwise specified in the end product specifications, fastener hardware shall have Class 3 thickness plating. (see 4.5.1 and 6.5). There shall be no bare areas.

3.3.1.2 For other than fastener hardware. For other than fastener hardware, the cadmium plating shall be Class 1 thickness unless otherwise specified in the contract or order or controlled by the following exceptions (see 6.2):

(a) Articles with portions externally threaded shall have a minimum of class 2 thickness on the threaded portions
(b) Holes and other openings and articles with internal threads from which the external environment is completely excluded shall not be subjected to thickness requirements but shall show evidence of coating. There shall be no bare areas.

TABLE I. Thickness

Class	Thickness	
	Inch minimum	Equivalent thickness micrometers (approx) 1/
1	0.0005	13
2	0.0003	8
3	0.0002	5

1/ 0.001 inch = 1 mil = 25.4 micrometers (microns).

3.3.2 Types. Unless otherwise specified in the contract or order (see 6.2), the cadmium plating shall be Type II. For use on surfaces to be painted, the cadmium plating shall be either Type II or Type III (see 6.1.2 and 6.1.3).

3.3.3 Adhesion. The adhesion of the plating shall be such that when examined at a magnification of approximately 4 diameters, the plating shall not show separation from the basis metal or from any underplating at the interface, nor shall any underplate show separation from the basis metal at the interface when subjected to the tests described in 4.5.2. The interface between the plating and either the basis metal or the underplate is the surface before plating. The interface between the underplate and the basis metal is the surface before underplating. The formation of cracks in the plating caused by rupture of the basis metal, the underplate or combination of both which do not result in flaking, peeling or blistering of the plating shall not be considered as nonconformance to this requirement.

3.3.4 Corrosion resistance. Cadmium plating with the Type II treatment shall show neither white corrosion products of cadmium nor basis metal corrosion products at the end of 96 hours when tested by continuous exposure to the salt spray in accordance with 4.5.3. The appearance of corrosion products, visible to the unaided eye at normal reading distance shall be cause for rejection, except that white corrosion products at the edges of specimens shall not constitute failure.

3.4 Workmanship.

3.4.1 Basis metal. The basis metal shall be free from visible defects that will be detrimental to the appearance or protective value of the plating. The basis metal shall be subject to such cleaning and plating procedures as necessary to yield platings herein specified.

3.4.2 Plating. The cadmium plating shall be smooth, fine grained, adherent, uniform in appearance, free from blisters, pits, nodules, burning and other defects. The plating shall show no indication of contamination or improper operation of equipment used to produce the cadmium deposit, such as excessively powdered or darkened platings. Superficial staining which has been demonstrated as resulting from rinsing or slight discoloration resulting from any drying or baking operation as specified (see 3.2.8) shall not be cause for rejection. All details of workmanship shall conform to the best practice for quality plating.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Classification of inspection. The inspection requirements specified herein are classified as follows:

(a) Production control inspection (see 4.3)
(b) Quality conformance inspection (see 4.4)

4.3 Production control inspection.

4.3.1 Control records. When specified in the contract or order (see 6.2), the supplier shall maintain a record of each processing bath, showing all additional chemicals or treatment solutions to the unit, the results of all analyses performed and the quantity of parts plated during operation. Upon request of the procuring activity, such records shall be made available. These records shall be maintained for not less than one year after completion of the contract or purchase order.

4.3.2 Production control. The equipment, procedures and operations employed by a supplier shall be capable of producing high quality electrodeposited cadmium plating on materials as specified in this document. When specified by the procuring activity (see 6.2), the supplier, prior to production, shall demonstrate the capability of the process used to show freedom from hydrogen embrittlement damage as indicated by satisfactory behavior of specimens prepared (see 6.2.2) and tested in accordance with 4.3.2.1 to comply to the requirements of MIL-S-5002 for preproduction process qualification.

4.3.2.1 Preproduction control. For preproduction control four round notched steel specimens shall be prepared in accordance with 4.4.4.3 from four individual heats for a total of 16 specimens, using the specified steel alloy for which preproduction examination of the process is to be demonstrated. Specimens shall be heat treated to the maximum tensile strength representing production usage. The specimens shall be given the same pre-treatments, electroplating and post-plating treatments proposed for production. The specimens shall be subject to test detailed in 4.5.4. The process shall be considered satisfactory if all specimens show no indication of cracks or failure. The tests results and production control information shall be submitted to the procuring activity for approval. Until approval has been received, parts shall not be plated.

4.3.3 Frequency of tests. To assure continuous control of the process as required by MIL-S-5002 and to prevent detrimental hydrogen embrittlement during production, the satisfactory behavior of specimens, prepared and tested in accordance with Table II, shall be made once each month or more frequently if required by the procuring activity. The results of tests made to determine conformance of electrodeposited platings to all requirements of this specification for definite contracts or purchase order are acceptable as evidence of the properties being obtained with the equipment and procedures employed.

4.3.4 Production control specimens. Test specimens for production control shall be prepared in accordance with 4.4.4, 4.4.4.1 and 4.4.4.2 as applicable for the thickness, adhesion and corrosion resistance tests detailed in Table II. Specimens for the production control embrittlement relief test shall be four round notched steel specimens of alloy steel 4340 conforming to QQ-S-624, heat treated to the maximum tensile strength, from one or more heats, and prepared in accordance with 4.4.4.3.

Table II. Production Control Tests and Specimens

Test	For coating types	Requirement paragraphs	Specimen preparation paragraphs	Test reference paragraphs
Thickness	I, II, III	3.3.1, 3.3.1.1 and 3.3.1.2	4.4.4 and 4.4.4.1 1/	4.5.1
Adhesion	I, II, III	3.3.3	4.4.4 and 4.4.4.1 1/	4.5.2
Corrosion resistance	II	3.3.4	4.4.4 and 4.4.4.2 1/	4.5.3
Hydrogen embrittlement	I, II, III	3.2.8	4.3.4, 4.4.4, and 4.4.4.3	4.5.4

1/ Standard alloy steels shall be used for production control specimens. The selection shall be at the option of the supplier; however alloy steels such as AISI or SAE numbers 4130, 4135, 4140, 4145, 4340, 8645 and 8740 conforming to QQ-S-624 shall be used.

4.4 Quality conformance inspection

4.4.1 Lot. A lot shall consist of plated articles of the same basis metal composition, class and type plated and treated under the same conditions and approximately the same size and shape submitted for inspection at one time.

4.4.2 Sampling for visual examination and non destructive tests. Sampling for visual examination and non destructive tests shall be conducted at the option of the supplier in accordance with MIL-STD-105 or using Table III. A sample of coated parts or articles, except for those barrel plated, shall be drawn by taking a random from each lot the number of articles in accordance with MIL-STD-105, Level II, Acceptable Quality Level (AQL) 1.5 percent defective, or as indicated in Table III. Barrel plated parts or articles shall be sampled in accordance with Level S-3 of MIL-STD-105, Acceptable Quality Level (AQL) 4.0 percent defective. The lot shall be accepted or rejected according to the procedures in 4.4.2.1 for visual examination and 4.4.2.2 for plating thickness (non destructive tests).

TABLE III. Sampling for visual examination and nondestructive tests

Numbers of items in lot inspections	Number of items in samples (randomly selected)	Acceptance number (maximum number of sample items nonconforming to any test)
15 or less	7 1/	0
16 to 40	10	0
41 to 110	15	0
111 to 300	25	1
301 to 500	35	1
501 and over	50	2

1/ If the number of items in the inspection lot is less than 7, the number of items in the sample shall equal the number of items in the inspection lot.

4.4.2.1 Visual examination. Samples selected in accordance with 4.4.2 shall be examined for compliance with requirements of 3.4.2 after plating. If the number of non conforming articles exceeds the acceptance number for the sample, the lot represented by the sample shall be rejected.

4.4.2.2 Thickness of plating (nondestructive tests). Samples selected in accordance with 4.4.2 shall be inspected and the plating thickness measured by the applicable tests detailed in 4.5.1, at several locations on each article as defined in 3.3.1, 3.3.1.1 or 3.3.1.2, as applicable, for compliance with the requirements. Measurements on fastener hardware (see 3.3.1.1) shall be made at locations defined in MIL-STD-1312, Test 12. The part or article shall be considered nonconforming if one or more measurements fail to meet the specified minimum thickness. If the number of defective items in any sample exceeds the acceptance number for the specified sample, the lot represented by the sample shall be rejected. Separate specimens (see 4.4.4.1) shall not be used for thickness measurements unless a need has been demonstrated.

4.4.3 Sampling for destructive tests. A random sample of four plated parts or articles shall be taken from each lot for each destructive test or separately plated specimens shall be prepared in accordance with 4.4.4, 4.4.4.1, 4.4.4.2 and 4.4.4.3 to represent each lot. If the number of articles in the lot is four or less, the number of articles in the sample shall be specified by the procuring activity (see 6.2).

4.4.3.1 Thickness of plating (destructive tests). If sampling and testing for thickness of plating by nondestructive testing is not the option of the supplier, samples selected in accordance with 4.4.3 shall be measured for plating thickness by the applicable test detailed in 4.5.1, at several locations on each article as defined in 3.3.1, 3.3.1.1 or 3.3.1.2 for compliance with the requirements. Measurements on fastener hardware (see 3.3.1.1) shall be made at locations defined in MIL-STD-1312, Test 12. If the plating thickness at any place on any article or specimen is less than the specified minimum thickness, the lot shall be rejected. Separate specimens (see 4.4.4.1) shall not be used for thickness measurements unless a need has been demonstrated.

4.4.3.2 Adhesion (destructive tests). The articles or specimens used for the destructive thickness test (see 4.4.3.1), if of suitable size and form, may be used as the test pieces for the adhesion test to determine compliance with the requirements of 3.3.3. Failure of one or more of the test pieces shall constitute failure of the lot.

4.4.3.3 Corrosion resistance (destructive tests). When specified in the contract or order, compliance with the requirements for corrosion resistance of Type II treated articles shall be determined (see 6.2). A set of four separate test specimens, prepared in accordance with 4.4.4 and 4.4.4.2 in lieu of the treated coated articles shall be used to determine compliance with the requirements for corrosion resistance (see 3.3.4). Failure of one or more of the test specimens shall reject the lot.

4.4.3.4 Hydrogen embrittlement relief (destructive tests). When specified in the contract or order, conformance to the requirements of 3.2.8 for hydrogen embrittlement relief of treated parts shall be determined for those parts which will be subject to a sustained tensile load in use (see 6.2). A random sample of four plated articles shall be taken from each lot of four specimens, prepared in accordance with 4.4.4 and 4.4.4.3, shall be used to represent the lot. When tested as specified in 4.5.4, cracks or failure by fracture shall be cause for rejection. Failure of one or more of the test pieces shall reject the lot.

4.4.4 Quality conformance specimen preparation. When the plated articles are of such form, shape, size and value as to prohibit use thereof, or are not readily adaptable to a test specified herein, or when destructive tests of small lot sizes are required the test shall be made by the use of separate specimens plated concurrently with the articles represented. The separate specimens shall be of a basis metal equivalent to that of the articles represented. "Equivalent" basis metal includes chemical composition, grade, condition and finish of surface prior to plating. For example, a cold-rolled steel surface should not be used to represent a hot-rolled steel surface. Due to the impracticality of forging or casting separate test specimens, hot-rolled steel specimens may be used to represent forged and cast-steel articles. The separate specimens may be also cut from scrap castings when ferrous alloy castings are being plated. These separate specimens shall be introduced into a lot at regular intervals prior to the cleaning operations, preliminary to plating, and shall not be separated therefrom until after completion of plating. Conditions affecting the plating of specimens including the spacing and plating media, bath agitation, temperature, etc. in respect to other objects being plated shall correspond as nearly as possible to those affecting the significant surfaces of the articles represented. Separate specimens shall not be used for thickness measurements, however, unless the necessity for their use has been demonstrated.

4.4.4.1 Specimens for thickness and adhesion tests. If separate specimens for thickness and adhesion tests are required, they shall be strips approximately 1 inch wide, 4 inches long and 0.04 inch thick.

4.4.4.2 Specimens for corrosion resistance tests. If separate specimens for corrosion resistance test are required, they shall be panels not less than 6 inches in length, 4 inches in width and approximately 0.04 inch thick.

4.4.4.3 Specimens for embrittlement relief. Separate specimens for embrittlement relief test shall be round notched specimens with the axis of the specimen (load direction) perpendicular to the short transverse grain flow direction. The configuration shall be in accordance with figure 8 of ASTM E8 for rounded specimens. Specimens shall have a 60 degree V-notch located approximately at the center of the gage length. The cross section area at the root of the vee shall be approximately equal to half the area of the full cross section area of the specimen's reduced section. The vee shall have a 0.010 $\pm$ 0.0005 radius of curvature at the base of the notch (see 6.2.2).

4.5 Tests.

4.5.1 Thickness. For nondestructive measuring of plating thickness, procedures in accordance with Fed. Test Method Std. No. 151, Method 520 (electronic test), ASTM B499 (magnetic test), ASTM B529 (eddy current), ASTM B567 (test by beta radiation back scatter principle) or ASTM B568 (X-ray spectrometry) may be used. For destructive measuring of plating thickness, procedures in accordance with ASTM B487 (microscopic) or ASTM B504 (coulometric) may be used. In addition to the above, the other procedures embodied in MIL-STD-1312, Test 12 may be used for thickness measurement of plating fastener hardware. Thickness measurements of cadmium platings, Types II and III, shall be made after application of the supplementary treatments. When the coulometric test is used, the supplementary treatment shall be removed prior to testing. The chromate film may be removed from Type II coating by using a very mild abrasive (a paste of levigated alumina rubbed on with the finger). The phosphate coating may be removed from the type III coating by immersing the specimen in a 10 percent solution of NaOH and scrubbing with a rubber policeman (usually takes from 10 to 15 minutes).

4.5.2 Adhesion. Adhesion may be determined by scraping the surface or shearing with a sharp edge, knife, or razor through the plating down to the basis metal and examining at four diameters magnification for evidence of non-adhesion. Alternately, the article or specimen may be clamped in a vise and the projecting portion bent back and forth until rupture occurs. If the edge of the ruptured plating can be peeled back or if separation between the plating and basis metal can be seen at the point of rupture when examined at four diameters magnification, adhesion is not satisfactory.

4.5.3 Corrosion resistance. Corrosion resistance shall be conducted in accordance with ASTM B117 (salt spray test) for 96 hours or in accordance with MIL-STD-1312, Test 1 for fastener hardware. To secure uniformity of results, type II supplementary coatings shall be aged at room temperature for 24 hours before subjection to the salt spray.

4.5.4 Embrittlement relief. Compliance with 3.2.8 shall be determined with samples of plated parts taken as specified in 4.4.3.4. Parts such as spring pins, lock rings, etc., which are installed in holes or rods shall be similarly assembled using the applicable parts specifications or drawing tolerances which impose the maximum sustained tensile load on the plated part. The selected samples shall be subjected to a sustained tensile load equal to 115 percent of the maximum design yield load for which the part was designed. Fastener hardware, where the maximum design yield load is not known or given, shall be tested in accordance with MIL-STD-1312, Test 5. Parts which require special fixtures, extreme loads to comply with the above requirements, or where the maximum design yield load is not known, may be represented by separate specimens prepared in accordance with 4.4.4.3. The notched specimens shall be subject to a sustained tensile load equal to 75 percent of the ultimate notch tensile strength of the material. The articles, parts or specimens shall be held under load for at least 200 hours and then examined for cracks or fracture.

5. PREPARATION FOR DELIVERY

5.1 Packaging and packing. Preservation, packaging and packing methods for electrodeposited cadmium plated parts or articles employed by a supplier shall be such as to preclude damaging during shipment and handling.

6. NOTES

6.1 Intended use.

6.1.1 Use. The electrodeposited cadmium platings covered by this specification are intended for use as corrosion protective platings on ferrous and other basis metal parts. On ferrous parts heat-treated or having an ultimate strength between 180,000 to 240,000 psi (approximately Rockwell C40 to C49), such processing should be used for cleaning and cadmium deposition by electroplating that little or no hydrogen embrittlement will result. On steel heat-treated or having an ultimate strength greater than 240,000 psi, cadmium deposition by electrodeposition is not recomended.

6.1.2 Type II treatment. The prime purpose of chromate finishes (type II) on electrodeposited cadmium platings is to retard or prevent the formation of white corrosion products on surfaces exposed to stagnant water, high humidity atmospheres, salt water, marine atmospheres or cyclic condensation and drying. Some types of chromate coatings have proved satisfactory as a base for paints.

6.1.3 Type III treatment. The prime purpose of phosphate finishes (type III) on electrodeposited cadmium platings is to form a paint base.

6.2 Ordering data. Purchasers should select the preferred options permitted herein and include the following information in procurement documents:

(a) Title, number and date of this specification

(b) Class and Type required (see 1.2.1, 1.2.2, and 3.3.2)

(c) When plating is to be applied, if other than specified (see 3.2.1, 3.2.4, and 3.2.6)

(d) Stress relief treatment, if other than specified (see 3.2.2)

(e) Cleaning of steel, if other than specified (see 3.2.3)

(f) Underplating required (see 3.2.5)

(g) Luster required, if other than specified (see 3.2.7)

(h) Hydrogen embrittlement relief treatment, if other than specified (see 3.2.8)

(i) Type of chromate treatment required for conversion to type II, if other than specified (see 3.2.9)

(j) Type of phosphate treatment required for conversion to type III, if other than specified (see 3.2.10)

(k) Thickness of coating, if other than specified (see 3.3.1, 3.3.1.1 and 3.3.1.2)

(l) Control record requirement (see 4.3.1)

(m) Preproduction control examination (see 4.3.2)

(n) Number of samples for destructive testing (see 4.4.3)

(o) Whether corrosion resistance test is required (see 4.4.3.3)

(p) Whether hydrogen embrittlement relief test is required (see 4.4.3.4)

6.2.1 The manufacturer of the basis metal parts should provide the plating facility with the following data:

(a) Hardness of steel parts (see 3.2.1)

(b) Heat treatment for stress relief, whether it has been performed or is required (see 3.2.2)

(c) Tensile loads required for embrittlement relief test, if applicable (see 4.5.4).

6.2.2 The manufacturer of the basis metal parts should provide the plating facility with notched tensile specimens (see 4.4.4.3) to be plated for conformance with 3.2.8 required for production control (see 4.3.2.1, and 4.3.4) and lot acceptance (see 4.4.3 and 4.4.3.4).

6.2.3 When QQ-P-416 is specified for articles to be surface finished, coatings of cadmium in accordance with MIL-C-81562, Coatings, Cadmium and Zinc (Mechanically Deposited), may be furnished in lieu of the electrodeposited coating at the option of the supplier, within the limitations of this specification and upon acceptance and approval of the procuring activity.

6.2.4 Information relative to an alternate process should be furnished to the cognizant Government activity for approval prior to use on the item under consideration.

6.3 Limitations. Cadmium platings should not be used on parts for space applications or on parts which in service reach a temperature of 450°F (233°C) or higher or come in contact with other parts which reach those temperatures. MIL-S-5002 contains additional warning where the cadmium plating shall not be used for weapons systems applications.

6.4 Stress relief. There is a hazard that hardened and tempered cold-worked or cold-straightened steel parts may crack during cleaning and plating. Such parts should have a suitable heat treatment for stress relief prior to cleaning and plating (see 3.2.2).

6.5 Threaded parts. As heavier platings are required for satisfactory corrosion resistance than class 3 for military use, allowance should be made in the manufacture of most threaded articles, such as nuts, bolts and similar fasteners with complementary threads for dimensional tolerances to obtain necessary coating build-up. Certain recessed areas, such as root diameters of threads, have a tendency to exhibit lack of build-up with electrodeposited platings and vacuum deposited cadmium in contrast with mechanically deposited cadmium coatings.

6.6 Baking time. For high strength materials (Rockwell C40 and above), it may be beneficial to extend the baking time to 23 hours to insure complete hydrogen embrittlement relief.

6.7 Type II temperature limitations. Chromate treatments (Type II) should not be used on plated parts that will not be painted and which will be continuously exposed to temperatures in excess of 150°F (66°C) or intermittently exposed for short periods to temperatures of approximately 300°F (131°C) or more. However, these treatments may be used to prevent finger marking and corrosion which may occur at room temperature during assembly and storage.

6.8 Type II handling precaution. Chromate treatments (type II), which involve only dipping in chemical solutions, normally require a sufficient period of drying, approximately 24 hours at 70 to 90°F (21 to 32°C) to render the parts suitable for handling without damage to the coating while in gelatinous forms; and it is important with such coatings that the workmanship be such that the coating is not excessively damaged while wet.

6.9 Reactivation. Surfaces of cadmium plating intended for conversion to type II and which have become passive as a result of the baking operation specified in 3.3.6 may be reactivated by brief immersion in dilute acid. If, for example, the chromating solution is acidified with sulfuric acid, then the reactivating solution should be 1 part sulfuric acid (sp. gr. 1.83) by volume added to 99 parts water, or for further example, if the chromating solution is acidified with hydrochloric acid, then the activating solution should be 1 part hydrochloric acid (sp. gr. 1.16) by volume added to 99 parts water. The duration of immersion should be as brief as is consistent with the nature of the work. For example, a perforated container of barrel-plated parts would be expected to be reactivated in approximately 15 seconds and separately racked items in approximately 5 seconds. The surfaces should be activated as soon as possible following baking operation and should be handled carefully to avoid contamination by dirt or grease.

6.10 Toxicity. Cadmium, because of its toxicity, shall not be employed as a plating for any object intended for use as a food container or cooking utensil or for any object likely to come in contact with food. Cadmium plated sheets and any other structural shapes which may be subjected to heat from welding, brazing or soldering operations should be so labeled because of the danger from poisonous vapors during operations.

6.11 Packaging limitations. Unprotected cadmium plated articles should not be packed in non-ventilated containers, either together or in contact with electrical equipment, because of the danger of deleterious effect on cadmium plating from unstable organic electrical insulation. In addition to organic electrical insulation, phenolic resinous substances and other containing unsaturated carbon-to-carbon linkages, such as oil paints and impregnated paper, etc., cause an abnormal attack on cadmium by setting free in the presence of moisture formic acid, butyric acid, etc. Corrosion of cadmium platings and steel basis metal has been noted when cadmium plated articles have been packaged in direct contact with container materials such as wood or cardboard. Corrosion has been especially severe if the container materials have become wet or have been stored under conditions of high humidity.

MILITARY INTEREST:

Custodians

Army - MR
Navy - AS
Air Force - 20

Review Activities

Army - AL, AR, ER
Navy - EC, OS
Air Force - 70, 99
DLA - IS(E)

User Activities

Army - AT, ME, MI
Navy - MC, YD

CIVIL AGENCY COORDINATING ACTIVITIES:

GSA - FSS
COM - NBS

PREPARING ACTIVITY:

NAVY - AS

DOD Project MFFP-0373

Orders for this publication are to be placed with the General Services Administration, acting as an agent for the Superintendent of Documents. See Section 2 of this specifciation to obtain extra copies and other documents referenced herein.

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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
QQ-P-416E	PLATING, CADMIUM (ELECTRODEPOSITED)

3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR ☐ USER ☐ MANUFACTURER ☐ OTHER *(Specify)*:
b. ADDRESS *(Street, City, State, ZIP Code)*	

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional	8. DATE OF SUBMISSION *(YYMMDD)*

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APPENDIX C

MILITARY SPECIFICATION (MIL-C-83488C) FOR ALUMINUMM ION VAPOR DEPOSITION

MILITARY SPECIFICATION

COATING, ALUMINUM, HIGH PURITY

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification establishes the requirements for coating low alloy steel, stainless steel, aluminum alloy and titanium alloy parts with high purity aluminum (99 percent plus).

1.2 Classification.

1.2.1 Classes. High Purity aluminum coatings shall be of the following classes, as specified (See 3.5 and 6.2):

Class 1 - 0.0010 inch thick (0.026 mm) (min)
Class 2 - 0.0005 inch thick (0.013 mm) (min)
Class 3 - 0.0003 inch thick (0.008 mm) (min).

1.2.2 Types. High purity aluminum coatings shall be of the following types as specified (See 6.2):

Type I - as coated
Type II - with supplementary chromate treatment (See 3.4).

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: AFWAL/MLSE, Standardization Manager, WPAFB, OH 45433 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

AREA MFFP

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified, the following specifications, standards, and handbooks of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DODISS) specified in the solicitation form a part of this specification to the extent specified herein.

SPECIFICATIONS

FEDERAL

QQ-A-225/1	Aluminum Alloy Bar, Rods, and Wire, Rolled, Drawn, or Cold Finished, 1100
QQ-A-250/4	Aluminum Alloy 2024, Plate and Sheet

MILITARY

MIL-S-5002	Surface Treatments and Metallic Coatings for Metallic Surfaces of Weapon Systems
MIL-C-5541	Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys
MIL-T-9046	Titanium and Titanium Alloy, Sheet, Strip and Plate
MIL-S-18729	Steel Plate, Sheet and Strip, Alloy 4130 Aircraft Quality

STANDARDS

FEDERAL

FED-STD-151	Metals; Test Methods

MILITARY

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes

(Copies of specifications, standards, drawings, and publications required by manufacturers in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. The issues of the documents which are indicated as DOD adopted shall be the issue listed in the current DODISS and the supplement thereto, if applicable.

ASTM B117	Salt Spray (Fog) Testing
ASTM B499	Measuring Coating Thickness by the Magnetic Method Nonmagnetic Coatings on Magnetic Basis Metal

(Applications for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

(Industry association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

2.3 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

3. REQUIREMENTS

3.1 Materials. The materials used shall be such as to produce aluminum coatings which conform to this specification.

3.1.1 Composition. The composition of the coating shall be not less than 99.0 percent aluminum.

3.2 Equipment and processes. The equipment and processes employed to produce high purity aluminum coatings shall be capable of providing a uniform coating in accordance with the detailed requirements of this specification.

3.2.1 Process. The process used to deposit the coating shall be such that a temperature rise in the parts shall not occur that will cause adverse action between the coating and the substrate, or adverse effects to the substrate.

3.2.1.1 Cleaning. All basis metals shall be cleaned in accordance with MIL-S-5002 prior to coating with high purity aluminum.

3.3 Areas of deposit. The coating shall completely cover all visible surfaces, including roots of threads, recesses, and sharp corners. The coating shall be deposited directly on the basis metal without a preliminary coating of other metal.

3.4 Supplementary chromate treatment (Type II). Unless otherwise specified, the high purity coating shall be Type II, which is a Type I coating with a supplementary chromate treatment in accordance with MIL-C-5541, Class 1A. Chromate treated parts, other than fasteners, should receive additional protective coatings. Applications requiring electrical conductivity (See 6.1) shall be chromate treated with a MIL-C-5541 solution which meets both Class 1A (Corrosion resistance and Class 3 (low electrical resistance) requirements.

3.5 Thickness of coating. The thickness of high purity aluminum shall be as specified in 1.2.1 on all visible surfaces except as specified in 3.5.3.

3.5.1 Class 1 thickness. Class 1 thickness shall be used when no additional paint finish is required. Class 1 thickness is recommended for high temperature applications and exterior applications where tolerance will permit.

3.5.2 Class 2 thickness. Class 2 thickness is recommended for interior applications or where class 1 thickness is unacceptable for dimensional thickness reasons.

3.5.3 Exceptions to Class 1, Class 2 and Class 3 thicknesses. Holes, recesses, internal threads, and other areas where a controlled deposit cannot normally be obtained shall not be subject to a thickness requirement, but there shall be no bare areas.

3.6 Stripping of aluminum coatings. Parts to be recoated shall be stripped by mechanical means or in a suitable caustic solution. If stripped with caustic solution, steel parts having hardness of Rockwell C-40 or greater shall be baked after stripping at 375°F ± 25°F for three hours minimum to relieve any hydrogen embrittlement in the basic metal.

3.7 Corrosion resistance. Test specimens shall show no evidence of corrosion of the basis metal when exposed for the periods of time shown in Table I in accordance with the method specified in 4.5.3. The appearance of white corrosion products on the aluminum coating during the test period shall not be cause for rejection.

TABLE I. Salt spray test.

Class	Test period (hours)	
	Type I	Type II
1	504	672
2	336	504
3	168	336

3.8 Adhesion. The adhesion of the coating shall be such that when examined at a minimum magnification of approximately four diameters it does not show separation from the basis metal at the interface, when subjected to the test specified in 4.5.2. The interface between the aluminum and the basis metal is the surface of the basis metal before coating. The formation of cracks in the deposit caused by rupture of the basis metal which does not result in flaking, peeling, or blistering of the deposit shall not be considered as nonconformance to this requirement.

3.9 Workmanship.

3.9.1 Basis metal. The basis metal shall be substantially free from defects that will be detrimental to the appearance or the protective value of the coating.

3.9.2 Coating. The high purity aluminum coating shall be smooth, fine grained, adherent, uniform in appearance, free from staining, pits, burning porosity and other defects. The coating shall show no indication of contamination or improper operation of equipment used to produce the deposit, such as excessively powdered or darkened coatings. All details of workmanship shall conform to the best practice for high quality coating. Type II parts processed in accordance with MIL-C-5541 requirements shall have a continuous, distinctly colored protective film ranging in color from yellow and iridescent bronze through olive drab and brown.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification. All the tests required herein for the testing of high purity aluminum coatings are classified as quality conformance tests, for which necessary sampling techniques and the methods of testing are specified in this section.

4.3 Test specimens. When the coated articles are of such form or material as to be not readily adaptable to a test specified herein, or for destructive tests, or for the sampling of small lot sizes, the tests shall be made by the use of separate specimens coated concurrently with the articles represented. The separate specimens shall be of a basis metal, equivalent to that of the articles represented, (or per 4.3.2 thru 4.3.5) except that corrosion resistance (see 3.7) shall be determined by coating 4130 alloy steel specimens.

4.3.1 Separate specimens. The separate specimens shall be strips approximately 1 inch wide, 4 inches long, and 0.04 inch thick, for adhesion and thickness tests, but shall be at least 3 inches wide, 6 inches long, and any convenient thickness for corrosion tests. These specimens shall be introduced into a lot at regular intervals prior to the cleaning operation preliminary to coating and shall not be separated therefrom until after completion of the processing. Conditions affecting the coating of the specimens, including the spacing and positioning with respect to vapor source and to other objects being coated, shall correspond as nearly as possible to those affecting the significant surfaces of the articles represented. Separate specimens shall not be used for thickness measurements unless the necessity for their use has been demonstrated.

4.3.2 Steel parts. Metal strips approximately 1 inch by 4 inches by .040 inch, AISI 4130, (MIL-S-18729) or equivalent for coating adhesion test for steel parts.

4.3.3 Titanium parts. Metal strips approximately 1 inch by 4 inches by .040 inch, Ti-6Al-4V, (MIL-T-9046) or equivalent for coating adhesion test for titanium parts.

4.3.4 Aluminum parts. Metal strips approximately 1 inch by 4 inches by 0.40 inch, 2024-T81, (QQ-A-250/4) or equivalent for coating adhesion tests for aluminum parts.

4.3.5 Corrosion tests. Steel panels approximately 3 inches by 6 inches, AISI 4130, (MIL-S-18729) or equivalent for corrosion tests.

4.4 Sampling.

4.4.1 Lot. A lot shall consist of coated articles of approximately the same size, shape, type, and class of coating, coated in the same production run. In the case of short production runs, a lot for inspection purposes may be made up a group of small lots covering several orders of parts similar in size and shape and coated under similar conditions.

4.4.2. Sampling for destructive tests of coating. Random samples for the 4.5 test methods shall be taken as follows:

4.4.2.1 For thickness and adhesion. A random sample of two articles shall be taken from any inspection lot or two separately plated specimens shall be prepared in accordance with 4.3 to represent each inspection lot.

4.4.2.2 For corrosion resistance. A random sample of two articles shall be taken from any inspection lot at a minimum of one per month or two separately coated specimens shall be prepared in accordance with 4.3 to represent an inspection lot. Failure of any sample shall require random sampling as mentioned above for each inspection lot for five consecutive inspection lots without failure.

4.5 Test procedures.

4.5.1 Thickness. Thickness determinations shall be made by eddy current test, beta back scatter test, micrometer measurements, microscopic test, or magnetic test. The magnetic test is applicable only to ferrous alloy substrates. The microscopic test shall be made per Method 521 of FED-STD-151. The magnetic test shall be made per Method 522 of FED-STD-151. For reference tests, the microscopic test shall be used. If the thickness of the plating on an aluminum alloy part cannot suitably be measured with any of these devices, companion metal strips approximately 1 inch by 4 inches by .040 inch, AISI 4130, MIL-S-18729 or equivalent can be used.

4.5.2 Adhesion. Adhesion shall be determined by scraping the surface of the plated article to expose the basis metal and examining at a minimum of four diameters magnification for evidence of nonadhesion. Alternatively, the test strip shall be clamped in a vise and bent back and forth until strip rupture occurs. If the edge of the ruptured coating can be peeled back or if separation between the coating and the basis metal can be seen at the point of rupture when examined at four diameters magnification, adhesion is not satisfactory.

4.5.3 Corrosion resistance. The corrosion resistance test shall be conducted in accordance with the procedure specified in ASTM B-117 to determine conformance with 3.7.

5. PACKAGING

5.1 Packaging. There are no packaging, packing, or marking requirements applicable to this specification.

6. NOTES

6.1 Intended uses. The high purity aluminum coatings covered by this specification are intended for use as corrosion protective coatings on ferrous and aluminum alloy parts. Coating may be applied by any process which produces a high purity (99 percent plus) aluminum coating. The process should not cause hydrogen embrittlement of the basis metal. Ion vapor deposited aluminum and aluminum electrodeposited using an organic electrolyte are processes which meet this criteria. It can also be applied to titanium and stainless steel alloys to provide corrosion compatibility with aluminum structure. Type II (Chromated per 3.4) high purity aluminum coating can also be used for applications which require an electrically conductive surface such as electrical bonding and grounding, and EMI compatibility.

6.1.1 Class 1 and Class 2 coatings. Class 1 and Class 2 coatings are intended as general purpose coatings for corrosion protection of structural and functional ferrous and non-ferrous alloy components.

6.1.2 Class 3 coatings. Class 3 coatings are intended as special purpose coatings where dissimilar metal compatibility is required for close tolerance or threaded parts (such as bushings, pins, fasteners, etc).

6.2 Ordering data. Procurement documents should specify the following:

a. Title, number, and date of this specification.
b. Class and type of coating required (see 1.2).
c. Method of determining compliance with 4.3.

6.2.1 Options. Any desired options offered herein may be utilized in procurement documents.

6.3 Reagent for microscopic determination. The following typical reagent is satisfactory for etching aluminum coatings on steel for microscopic determination of coating thickness:

10 percent weight NaOH.

6.4 Dimensional tolerance. The dimensional tolerance of most threaded articles, such as nuts, bolts, and similar fasteners with complementary threads do not permit the application of a coating thickness much greater than Class 3. If heavier coatings are required for satisfactory corrosion resistance, allowance must be made in the manufacture of the threaded fasteners for tolerance necessary for coating build-up.

6.5 Samples. It is believed that this specification adequately describes the characteristics necessary to secure the desired material, and that, normally, no samples will be necessary prior to award to determine compliance with this specification. If, for any particular purpose, samples with bids are necessary, they should be specifically asked for in the invitation for bids, and the particular purpose to be served by the bid sample should be definitely stated. The specification will apply in all other respects.

6.6 Changes from previous issue. Asterisks are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodian:
Air Force - 20
Navy - AS
Army - MR

Preparing Activity:
Air Force - 20

(Project No. MFFP-0309)

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MIL-C-83488C	Coating, Aluminum High Purity

NAME OF SUBMITTING ORGANIZATION

ADDRESS *(Street, City, State, ZIP Code)*

4. TYPE OF ORGANIZATION *(Mark one)*

- ☐ VENDOR
- ☐ USER
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- ☐ OTHER *(Specify)*: ______

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b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

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8. DATE OF SUBMISSION *(YYMMDD)*

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OF VALIDATION

MIL-C-83488C
NOTICE 1
30 July 1987

MILITARY SPECIFICATION

COATING, ALUMINUM, ION VAPOR DEPOSITED

MIL-C-83488C, dated 1 May 1985, has been reviewed and determined to be valid for use in acquisition.

Custodians:
Air Force - 20
Army - MR
Navy - AS

Preparing activity:
Air Force - 20

AMSC N/A

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APPENDIX D

TEST PLAN OVERVIEW

THE TEST PLAN

The Test Plan was issued as a separate document in September 1990.[3] This is an overview of the Test Plan. For a more detailed presentation of the Test Plan, the reader should refer to the September 1990 document.

D.1 Objectives

The Test Plan provided the planning and organization for the Test Program at Anniston Army Depot (ANAD). The Plan established what tests would be run and how the data from these tests would be collected, managed, and presented.

The Test Program had the primary objectives to (1) determine if the Aluminum Ion Vapor Deposition System (Ivadizer) was a viable alternative for the replacement of some or all cadmium electroplating, and (2) establish when and where the Ivadizer could replace cadmium plating.

Secondary objectives were (1) to develop the operating skills of Ivadizer operators, and (2) to establish Ivadizer operating parameters such as wire feed rate and ceramic boat speed traveling up and down the chamber so as to achieve reproducible coatings that satisfy all specification, including coating thickness, adherence, corrosion protection, and appearance.

D.2 Test Plan Outline

The Test Plan had two phases: Phase 1 and Phase 2. Test coupons and scrap parts were to be run during Phase 1. Test coupons are sheet metal strips, typically four inches by one inch and 0.040 inch thick. The test coupons served three important functions. One was to measure the adherence of the aluminum coating through destructive testing by repeatedly flexing the coupon until it broke. The second was to provide a reference point to compare different run conditions by measuring the thickness of the deposited aluminum coatings on the coupons. If different configurations of ceramic boat speed, wire feed rate, loading and configuration of parts, and type of parts being run provided the same coating thickness on the coupons, then run conditions could be defined as equivalent. Therefore, test coupons were very useful in establishing Ivadizer operating parameters. The third was to measure corrosion resistance by subjecting the coupons to a salt spray. Every Ivadizer run was to have at least six coupons. Two would be used to measure coating quality and thickness, two would be used to measure adhesion (with and without chromate conversion), and two would be used to measure corrosion resistance using salt spray testing. Test coupons were of the same base metals as the work run through the Ivadizer.

Scrap parts were very useful in establishing Ivadizer operating parameters, identifying parts that could be coated by the Ivadizer, and identifying parts that could be barrel coated. Barrel coating refers to placing small parts such as nuts, bolts, and screws inside a cylindrical, rotating, wire mesh container. Barrel coating is more convenient than individually suspending small parts by wires or hangers from a nonconducting rack. The salt spray test for corrosion resistance provided by a protective coating (ASTM Method B-117) requires that the part remain in the salt spray cabinet for a prescribed number of hours ranging from 168 to 672 hours. Scrap parts were preferable to production parts for salt spray testing in that usable parts were not taken out of service and the consequences of a coating failure were insignificant.

Phase 2 testing was to be based upon the Ivadizer operating parameters developed during Phase 1 and included production parts as well as scrap parts and test coupons. The criteria for scrap parts and test coupons were the same as those in Phase 1. The standard for production parts was that they could be returned to service and perform at least as well and as reliably as equivalent parts that had been cadmium plated.

D.3 Test Plan Data Collection

IT Corporation collected data on all test runs. Information was recorded on data logs while the runs were in process. Ultimately the data on the logs was transferred to an on-site computerized data base to supply data handling and reporting and more effectively manage the collated information. The computer software allowed sorting the data by any data field. This made it possible to identify parts that could be run in the Ivadizer either in a barrel coater or on a rack.

The test plan field test logs were revised during the testing. Operating experience revealed that test run results could be recorded on only two logs versus the eight listed in the Test Plan. This was due to anticipated variables such as precleaning procedures, orientation of parts on the rack, coating appearance and adhesion, corrosion resistance, glass peening requirements, and the ability to accept chromate conversion coatings having less impact than had been expected.

D.3.1 Run Log

Figure D-1 presents a Run Summary Form. The first page, Run Summary, describes the run conditions, the date, run of the day, and coating class and type. Next listed are the parameters that control the amount of aluminum evaporated and, therefore, the thickness of the coatings.

Wire feed rate is the rate at which aluminum wire is fed to the boats and vaporized. It is expressed as a percentage of the maximum possible feed rate. The faster the wire feed rate, the more aluminum is vaporized, and the thicker the coatings. Abar Ipsen Industries recommended a 35 percent wire feed rate. This recommendation was followed for almost every run and for all runs involving production parts. However, Titanium Finishing, Inc., of East Greenville, Pennsylvania, obtains good results with a 50 percent wire feed rate.

Boat speed is the speed at which the boats move up and down the Ivadizer chamber and is expressed as a percentage of the maximum possible boat speed. The greater the boat speed, the less time there is for aluminum to be fed into the boats and the thinner the coatings. The boats stop after each pass and the boat speed has to be reset for the next pass. Abar Ipsen recommended that coating take place in two or more passes with the first pass being at the fastest possible setting, 100 percent boat speed. This is to obtain a thin, uniform, adhering, initial coating of aluminum on the base metal surface. After the metal surface has been completely coated with aluminum, the process applies an aluminum coating on aluminum, which

I. RUN SUMMARY

Date	Run of day (1st, 2nd, etc.)	Coating		Wire feed rate, %	Boat speed, each pass, %				Plating time, min., for barrel, coating
		Class	Type		1st	2nd	3rd	4th	

Figure D-1. Run Log.

Figure D-1. (continued).

II. PARTS RUN

Part No.	Part description (shape and function)	Quantity of parts	Are any two part dimensions greater than five inches?	Are there any holes, cavities, or unusual configurations? If so, describe.

Figure D-1. (continued).

III. IMMEDIATE POST RUN EVALUATIONS

Part No.	Any apparent deficiencies, obvious thin areas, voids, non-adhering; if so, describe with locations on part

IV. POST RUN TESTING

Part No.	Thickness, mils (range)	Locations of thin areas (less than specification)	Salt spray Hour of testing, P/F	Chromate conversion or other post-treatment (P/F); if fail, describe failure and possible reasons

DISCUSS DEFICIENCIES AND FAILURES ON REVERSE SIDE, GIVING AS A MINIMUM, PART NUMBER AND DESCRIPTION, NUMBER OF PARTS AFFECTED, LOCATION ON PART, HOW SUSPENDED FROM THE PLATING RACK, CLEANING TECHNOLOGIES, ETC., AND POSSIBLE REASONS FOR THE DEFICIENCIES AND FAILURES.

is easier; a slower boat speed is desirable to achieve a thicker coating. A representative boat speed for a Class 3 type coating (0.3 mil minimum thickness) would be the first pass at 100 percent and a second pass at 70 percent.

For parts held in a rotating barrel, the Ivadizer boats are fixed beneath the barrel for a fixed time, such as 10 to 15 minutes. The process is controlled by this plating time and the wire feed rate.

The second page of the Parts Run form identifies the parts being run. Parts are identified by the Army Material Command Part Number, and the part description taken from the parts drawings if available. If unavailable, the part is described by shape and function. The quantity of each part being run is also recorded. Any configuration or shape of the part that might make the part difficult to run is listed. This includes holes and cavities that might be difficult to adequately cover or that could retain contaminants or moisture during cleaning and release them during plating.

The third page, Immediate Post Run Evaluation, allows listing any immediately apparent deficiencies such as areas not plated, obvious thinly plated areas, and non-adhering coatings.

The fourth page, Post Run Testing, lists results of subsequent testing and treatment of plated parts. Testing includes thickness measurements, testing for adhesion of the aluminum coating to the base metal surface, salt spray testing for corrosion resistance, and torsion testing for threaded parts. Post-Treatment was usually applying chromate conversion coating and was never a problem.

D.3.2 Parts Log

Figure D-2 shows a blank parts log form. The parts log lists all parts run in the Ivadizer by part number, part description, and the vehicle or engine where the part is used. Each time the part was processed in the Ivadizer, the parts log provides the date, class of coating, tests to which the part was subjected, and results of the tests (pass or fail). There was also a space for comments such as any difficulties that had been encountered in running the part in the Ivadizer.

PRODUCTION PARTS PROCESSED IN THE IVADIZER

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments

Figure D-2 Parts Log form.

D.4 Quality Assurance Provisions

Quality assurance provisions were conducted during the test program. The Test Plan, Abar Ipsen's manufacturer's manual, applicable military specifications, and applicable ASTM tests methods describe the quality assurance procedure in detail. Areas considered were:

- Vendors of aluminum wire and argon gas certified that their products met all applicable standards.
- All instrumentation was maintained and calibrated to conform with manufacturer's specifications. Records were maintained for all maintenance and calibration activities.
- The Ivadizer and grit-blasting and glass bead-peening cabinets used during the test were operated as recommended by the manufacturer. The grit-blasting and glass bead-peening cabinets were dedicated to Ivadizer service and were not used for other work.
- After cleaning and prior to processing, all parts were handled only by personnel wearing clean white cotton gloves. After cleaning, parts were moved into a dust-free, air-conditioned room and were coated within eight hours.
- Parts were inspected for coating appearance and thickness as described in Sections 4 and 5 of the Test Plan and the inspection logs. From each batch, a minimum of five parts or 50 percent of the total parts, whichever was greater, were formally inspected.
- All tests were carried out so as to conform with the requirements of the Test Plan.

APPENDIX E

DETAILED SUMMARY OF TEST CONDITIONS AND RESULTS

DETAILED SUMMARY OF TEST CONDITIONS

Table E-1 presents a summary of the test conditions and results obtained. Information presented is:

- Part number (if available),
- Part description (if available),
- Vehicle or engine where part is used, and
- Test results data - {test date, class of coating, pass (P) or fail (F) testing, type of testing (V = visual, T = thickness, CC = chromate conversion, SS = salt spray)}.

Thickness measurements were made on every type of part processed in a run. Coating thickness measurements were made on every part if five or less of that type were run. If more than five parts were run, measurements were made on at least half of the parts. Particular attention was given to thickness measurements near recessed areas, bends, and cavities.

A data sheet was completed for each Ivadizer run. These data sheets are presented in a separate document. Figure E-1 presents a representative completed Ivadizer run data sheet. The information on the first page, Run Summary, gives the run conditions. This run was the first of the day on March 11, 1991, and was a Class 3, Type II coating (the most common). The wire feed rate was 35 percent of the maximum possible wire feed rate. Abar Ipsen and McDonnell-Douglas recommended this rate, which was followed throughout the test program (experienced operators might wish to use other rates; a slower rate for coating threaded parts and a faster rate on other parts to increase production).

The boats holding the molten aluminum made two trips or passes up and down the plating chamber. The first pass was at the maximum possible speed (100 percent). The faster trip up and down the chamber meant that less aluminum was vaporized and the coating was thinner. After the part was completely coated with a thin aluminum coating, aluminum was being deposited upon aluminum, adhesion was less

TABLE E-1. PRODUCTION PARTS PROCESSED IN THE IVADIZER

(Test data; test date, class of coating, pass (P), or fail (F) testing; testing codes are V = visual, T = thickness, CC = chromate conversion, SS = salt spray)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
7398890		M60	3/13, 2 P (V, T)							
7404673	Spring, drivers seat compression	M60	3/1, 2 P (V, T)							
7973841	Gasket	1790 Eng	2/5, 3 P (V, T)							
W830010			2/19, 3 P (V, T)							
8619454	Mount, machined	M60	1/29, 3 P (V, T, cc)							
8619488	Support	M60	1/28, 3 P (V, T, cc)							
8725184	Retainer, crankshaft packing	1790 Eng	1/28, 3 P (V, T)	1/30, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	2/27, 3 P (V, T)			
8761080	Eye, engine lifting	M60	3/11, 3 P (V, T)							
8761083	Connector, cylinder head drain tube	M60	1/30, 3 P (V, T)							
8761088	Curved steel drain pipe	M60	3/11, 3 P (V, T)							
8761110	Neck, oil filter & indicator tube	M60	2/19, 3 P (V, T)							
8761111	Gas cap level	M60	11/28, 2 P (V, T)	12/15, 2 P (V) F (T)	1/24 2 P (V, T)	1/29, 3 P (V, T)	1/30, 3 P (V, T)			Positioning? 12/15, non-uniform coating with thin areas

(continued)

TABLE E-1. (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
8761138	Flange, intake manifold	1790 Eng	2/5, 3 P (V, T)	2/19, 3 P (V, T, CC)	1/24, 2 P (V, T)	3/5, 3 P (V, T)				
8781187		M60	1/29, 3 P (V, T)							
10527981	Threaded pin		3/11, 3 P (V, T)	3/12, 3 P (V, T, cc)						
10863824	Engine bolt	M60	3/14, 3 P (V, T)							
10865283	Flange, intercylinder camshaft screen	1790 Eng	1/28, 3 P (V, T)	2/5, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	3/11, 3 P (V, T)	3/12, 3 P (V, T)	3/13, 2 P (V, T)	
10865316	Angle bracket	1790 Eng	11/28, 3 P (V, T)	2/24, 2 P (V, T)	1/28, 3 P (V, T)	1/28, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T, cc)	2/27, 3 P (V, T)	Passed 4 other tests
10865331	Support, fuel injection line	1790 Eng	2/5, 3 P (V, T)	2/27, 3 P (V, T)	2/27, 3 P (V, T)	2/28, 3 P (V, T)	3/5, 3 P (V, T)			
10865332	Support, fuel injection line clamp	1790 Eng	1/31, 3 P (V, T)							
10865334	Support, fuel injection line clamp	1790 Eng	2/27, 3 P (V, T)	3/12, 3 P (V, T)	3/13, 3 P (V, T)					
10865335	Support, fuel injection line clamp	1790 Eng	11/27, 3 P (V, T)	2/20, 3 P (V, T)						
10865375	Bracket, angle	1790 Eng	12/10, 3 P (V, T)	12/12, 2 P (V, T, ss)	2/5, 3 P (V, T)	2/13, 2 P (V, T)	2/19, 3 P (V, T)	2/28, 3 P (V, T)	3/5, 3 P (V, T)	Passed 2 other tests
10873206	Wedge, prism lock	M60	1/15, 2 P (V, T)	1/23, 2 P (V, T)	1/28, 3 P (V, T)	2/27, 3 P (V, T)				1/23 Thin in recessed area, equivalent to cadmium plate

(continued)

TABLE E-1 (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
10873682		M60	3/11, 3 P (V, T)							
10882773		1790 Eng	3/11, 3 P (V, T)							
10915240	Pedal, brake	M60	1/30, 3 P (V, T)	2/14, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	3/13, 3 P (V, T)			
10935478	Spacer, sleeve	1790 Eng	2/27, 3 P (V, T)	2/27, 3 P (V, T)	2/28, 3 P (V, T)	2/28, 3 P (V				
10935619	Neck, oil filter & gage rod tubes	1790 Eng	1/15, 2 P (V, T)	1/29, 3 P (V, T)	3/5, 3 P (V, T)	2/4, 3 P (V, T)	2/28, 3 P (V, T)			1/15 Thin coating in-side neck, equivalent to cadmium plate
10941008	Tube, slotted guide, storage rack	M60	1/30, 3 P (V, T)	2/19, 3 P (V, T, cc)	2/27, 3 P (V, T, cc)	3/5, 3 P (V, T)	3/13, 3 P (V, T)			
10941018	Handle assembly	M60	2/5, 3 P (V, T)	2/28, 3 P (V, T)	3/5, 3 P (V, T)					
10948338	Housing for torsion bar	M551	2/23, 3 P (V, T, cc)							
10918349	Key, torque recoil guard	M551	3/1, 2 P (V, T)							
10948398	Torsion bar housing	M60	3/5, 3 P (V, T)							
10948664	Torsion bar	M551	2/4, 3 P (V, T)	2/5, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	2/27, 3 P (V, T)	3/12, 2 P (V, T)		
10953993	Spring, helical torsion	M60	3/1, 2 P (V, T)	3/5, 3 P (V, T)						

(continued)

TABLE E-1 . (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
10955921	Lever, door cupola	M551	2/5, 3 P (V, T, cc)	3/11, 3 P (V, T)						
10955925	Lever lock, door handle	M551	2/5, 3 P (V, T)							
11591586	Screen, air intake	M551	2/1, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)					
11636383	Ring, part of grenade launcher	M551	3/1, 2 P (V, T)	3/13, 2 P (V, T)	3/15, 2 P (V, T)					
11636384	Ring, part of grenade launcer	M551	3/1, 2 P (V, T)	3/13, 2 P (V, T)	3/15, 2 P (V, T)					
11643674	Tube, grenade launcher	M551	3/1, 2 P (V, T)	3/13, 2 P (V, T)	3/15, 2 P (V, T)					Good coating in all but 2" of tube
11664963	Tube assembly, grenade launcher	M551	3/1, 2 P (V, T)	3/13, 2 P (V, T)	3/15, 2 P (V, T)					
11655057	Wedge, vision block retainer	1790 Eng	1/29, 3 P (V, T)	1/30, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	3/13, 2 P (V, T)			
11682768	Bracket, cooling fan support	1790 Eng	11/28, 2 P (V, T, cc)	1/30, 3 P (V, T)	2/5, 3 P (V, T)	2/13, 3 P (V, T)	2/19, 3 P (V, T)	2/28, 3 P (V, T)	3/11, 3 P (V, T)	Passed two other tests
11683952	Connector, male	1790 Eng	12/4, 3 P (V, T, cc)	12/15, 2 P (V, T), F (ss)	1/30, 3 P (V, T, cc)	2/19, 3 P (V, T)				This part has a cavity at a 45° angle and requires careful positioning
11683970	Eye, engine lifting	1790 Eng	1/28, 3 P (V, T)	1/30, 3 P (V, T)						
11684019	Plate, mounting, fuel-water separator	1790 Eng	2/19, 3 P (V, T)	2/27, 3 P (V, T)	3/11, 3 P (V, T)	3/12, 3 P (V, T)				
11684020	Bracket, throttle control	1790 Eng	2/4, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)					

(continued)

TABLE E-1. (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
11684128	Bracket, angle	1790 Eng	1/22, 3 P (V, T)	1/29, 3 P (V, T)	2/29, 3 P (V, T)	2/28, 3 P (V, T)	1/22 coating was thin in a recessed area			
11684147		1790 Eng	3/12, 3 P (V, T)							
11684155		1790 Eng	3/12, 3 P (V, T)							
11684160	Support, fuel injection line	1790 Eng	1/28, 3 P (V, T)	1/31, 3 P (V, T)	2/5, 3 P (V, T)	2/19, 3 P (V, T, cc)	3/11, 3 P (V, T)	3/12, 3 P (V, T)		
11684234	Bracket, cooling fan shroud	1790 Eng	1/24, 2 P (V, T)	1/28, 3 P (V, T)	3/11, 3 P (V, T)	3/12, 3 P (V, T)				
12251905	Strap, blower motor	M60	1/17, 2 P (V, T)	1/22, 2 F? (V, T)	1/23, 3 P (V, T)	1/28, 3 P (V, T)	1/29, 3 P (V, T)	2/19, 3 P (V, T)	Pass 3 other tests. Jan 22 problem may be due to cleaning	
12254292	Bracket, cooling fan support	1790 Eng	1/24, 2 P (V, T)	3/5, 3 P (V, T)						
12254297	Spacer	1790 Eng	2/27, 3 P (V, T)	3/11, 3 P (V, T)	3/12, 3 P (V, T)					
12273826	Clamp	M1	2/5, 3 P (V, T)	2/19, 3 P (V, T, cc)						
12273827	Clamp	M1	3/12, 3 P (V, T)							
12274702	Link	M60	2/5, 3 P (V, T)							
12275001	Hook with eye	M60	1/30, 3 P (V, T)	2/4, 3 P (V, T)	2/19, 3 P (V, T)	2/27, 3 P (V, T)	2/27, 3 P (V, T)	2/28, 3 P (V, T)	3/5, 3 P (V, T)	
12275712	Bracket, solenoid	1790 Eng	1/24 2 P (V, T)	1/28, 3 P (V, T)	1/30 P (V, T)	2/4, 3 P (V, T)	2/28, 3 P (V, T)	3/5, 3 P (V, T)	3/11, P (V, T)	
12283742	Level	M60	3/11, 3 P (V, T)	3/12, 3 P (V, T)						

(continued)

TABLE E-1. (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
12285282	Bracket, alternator	1790 Eng	2/5, 3 P (V, T)	3/12, 3 P (V, T)						
12286282	Disk assembly, compressor rotor	M60	3/11, 3 P (V, T)							
12287034	Pin	M60	1/28, 3 P (V, T)	1/29, 3 P (V, T)	1/30, 3 P (V, T)	2/5, 3 P (V, T)	2/27, 3 P (V, T)			
12287035	Pin, hinge	M60	1/30, 3 P (V, T)	2/27, 3 P (V, T)	3/13, 2 P (V, T)					
12288274A		M1	3/11, 3 P (V, T)	3/12, 3 P (V, T)						
12288274C		M1	3/11, 3 P (V, T)	3/12, 3 P (V, T)						
12288275		M1	3/11, 3 P (V, T)	3/12, 3 P (V, T)						
12288300		M1	3/11, 3 P (V, T)	3/12, 3 P (V, T)						
12304635	Helical spring	M60	1/23, 3 P (V, T)							
12311033		M1	3/12, 3 P (V, T)							
12324433			3/12, 3 P (V, T)							
	Door knob, threaded		1/29, 3 P (V, T)							
	Fuel cell cover	M60	1/30, 3 P (V, T)	2/27, 3 P (V, T cc)	3/13, 2 P (V, T)					
	Fuel tank screw cap		2/27, 3 P (V, T)							

(continued)

TABLE E-1. (continued)

Part No. (if available)	Part description (if available)	Vehicle or engine where part is used	1st Test	2nd Test	3rd Test	4th Test	5th Test	6th Test	7th Test	Comments
	Heater part	M60	2/28, 3 P (V, T)							
	Latch for telescope	M551	2/28, 3 P (V, T)							
	Plunger on escape hatch	M551	2/27, 3 P (V, T, cc)							
	Solenoid plate	M60	2/27, 3 P (V, T, CC)							
	Spring, 2" long		2/19, 3 P (V, T)	3/11, 3 P (V, T)						
	Spring, 7" long		2/19, 3 P (V, T)	2/27, 3 P (V, T)						
	Thin cylinder, 3-3/4" diameter		2/27, 3 P (V, T, CC)	2/28, 3 P (V, T)	3/13, 2 P (V, T)					3/13 Thin on interior of cylinder
	Tube, hollow, 12" long, 3/4" diameter		2/19, 3 P (V, T, CC)	3/15, 2 P (V, T)						
	Tube, hollow, 9" long, 3/4" diameter		2/19, 3 P (V, T, CC)							

(continued)

I. RUN SUMMARY

Date	Run of day (1st, 2nd, etc.)	Coating		Wire feed rate, %	Boat speed, each pass, %				Plating time, min., for barrel, coating
		Class	Type		1st	2nd	3rd	4th	

Figure E-1. Completed Ivadizer Run Data Sheet.

Figure E-1 (continued)

II. PARTS RUN

Part No.	Part description (shape and function)	Quantity of parts	Are any two part dimensions greater than five inches?	Are there any holes, cavities, or unusual configurations? If so, describe.
8761080	Eye, engine lifting M60	1	No	No
8761088	Curved pipes, drain pipe M60	1	No	No
10527981	Threaded ring for telescope mast	3	No	No
10865283	Flange, intercylinder camshaft sleeve	1	No	No
10882773		1	No	No
11684019	Plate, mounting, fuel with supporter	1	No	No
11682768	Bracket, cooling for support	1	No	No
12275712	Bracket, solenoid	6	No	No
11684160	Support, fuel injection	1	No	No
10873682		1	No	No
11684156	Plate, fuel injection tube clamp	1	No	No
12254297	Spacer	1	No	No
12288300		2	No	No
12283742	Lever	2	No	No
11684234	Brackets, cooling fan shroud	1	No	No
12286282	Disc assembly, compressor rotor	2	No	No
12288275		1	No	No
8761088	Curved steel pipe, drain pipe	2	No	No
12288724A			No	No
12288274C	2" springs	3	No	No
10955921	Lever, door, cupola	3	No	No

Figure E-1. (continued)

III. IMMEDIATE POST RUN EVALUATIONS

Part No.	Any apparent deficiencies, obvious thin areas, voids, non-adhering; if so, describe with locations on part
	The curved steel pipe had a black discoloration, Peening removed it.

Figure E-1 (continued)

IV. POST RUN TESTING

Part No.	Thickness, mils (range)	Locations of thin areas (less than specification)	Salt spray Hour of testing, P/F	Chromate conversion or other post-treatment (P/F); if fail, describe failure and possible reasons
8761080	0.37 to 0.9			
8761088		Black, disappeared after peening		
10527981	0.5 to 0.8			
10865283	0.5 to 0.8			
10882773	0.5 to 0.8			
11684019	0.6 to 0.8			
11682768	0.6 to 0.9			
12275712	0.4 to 0.6			
11684160	0.3 to 0.8			
10873682	0.5 to 1.0			
11684156	0.7 to 1.0			
12254297	0.6 to 0.9			
12288300	0.5 to 0.9			
12283742	0.6 to 0.8			
11684234	0.3 to 0.4			
12286282	0.4 to 0.6			
12288275	0.5 to 1.0			
8761088	0.5 to 1.0			
12282274A	0.8 to 1.0			
12288274C	0.7 to 0.9			
2" springs	Ok vinyl			
10955921	0.5 to 1.0			

DISCUSS DEFICIENCIES AND FAILURES ON REVERSE SIDE, GIVING AS A MINIMUM, PART NUMBER AND DESCRIPTION, NUMBER OF PARTS AFFECTED, LOCATION ON PART, HOW SUSPENDED FROM THE PLATING RACK, CLEANING TECHNOLOGIES, ETC., AND POSSIBLE REASONS FOR THE DEFICIENCIES AND FAILURES.

of a problem, and a thick plating was possible. Hence, the second pass was at a slower boat speed corresponding to a thicker coating.

The second page of the data sheet, Parts Run, lists the parts that were processed in the run. The parts are identified by Part Number and Part Description as taken from the drawings, if available. If the Part Number and/or Part Description were not available, the part was identified by function (two-inch spring, for example), or by shape (curved steel pipe, drain-pipe).

Also listed was whether the part had two dimensions of five inches or greater. This would suggest that the part would need to be coated in two stages with the part being rotated after the first stage.

The form allows listing any holes, cavities, recesses, or unusual configurations that might be under coated. It was learned through operating experience that holes, cavities, etc., were much less of a problem than had been anticipated. The Ivadizer operators at ANAD were experienced cadmium electroplaters and they reported that the coverage in these areas was superior to ordinary cadmium electroplating.

The third page of the data sheet, Immediate Post Run Evaluation, provided an opportunity to list any apparent deficiencies or problems. On this run, the curved steel pipe (Part Number 8761088) had a dark black surface color. This color was removed by peening with glass beads, and the pipe had a satisfactory, shiny, metallic appearance.

The fourth page of the data sheet, Post Run Testing, describes tests run on the parts after coating. In this run, the coating thickness was measured on the parts and was expressed as a range from thinnest to thickest. At least three thickness measurements were made on each part. (The two-inch spring was an exception. The magnagauge probe could not make adequate contact with the thin coil surface and no measurements were taken.) All areas on all parts had at least the minimum thickness for a Class 3 coating, 0.3 mil.

The fourth sheet also provided space for listing other tests, such as applying chromate conversion coatings and adhesion. Aluminum coatings were always acceptable with respect to accepting chromate conversion and the coating adhesion.

SUMMARY OF ANNISTON ARMY DEPOT'S SALT SPRAY CABINET TEST OF IVADIZED COATINGS

Run date	Run no.	Coating class and type	Coating thickness (mils)	Test results: Adhesion	Test results: Corrosion resistance
11-19-90	3	3-II	0.3 to 0.6	Passed	Passed
11-27-90	1	3-II	0.3 to 0.7	Passed	Passed
12-04-90	1	3-II	0.4 to 0.6	Passed	Passed
12-04-90	2	3-II	0.4 to 0.7	Passed	Passed
12-05-90	2	3-II	0.3 to 0.5	Passed	Passed
12-12-90	2	3-II	0.3 to 0.6	Passed	Passed
12-13-90	1	3-II	0.3 to 0.7	Passed	Passed
1-15-91	1	2-II	a	Passed	Passed
1-16-91	1	2-II	a	Passed	Passed
1-16-91	2	3-II	b	Passed	Passed
1-17-91	1	2-II	a	Passed	Passed
1-22-91	1	2-II	a	Passed	Passed
1-22-91	2	3-II	b	Passed	Passed
1-23-91	1	3-II	b	Passed	Passed
1-23-91	2	3-II	b	Passed	Passed
1-24-91	1	3-II	b	Passed	Passed
1-25-91	1	3-II	b	Passed	Passed
1-28-91	1	2-II	a	Passed	Passed
1-29-91	1	2-II	a	Passed	Passed
1-29-91	2	3-II	b	Passed	Passed
1-30-91	1	3-II	b	Passed	Passed
1-31-91	2	2-II	a	Passed	Passed

[a] These were Class 2 coatings. Specifications are a minimum thickness of 0.5 mil.

[b] These were Class 3 coatings. Specifications are a minimum thickness of 0.3 mil.

APPENDIX F

PARTS IDENTIFIED BY ANNISTON ARMY DEPOT AS POTENTIAL IVADIZER CANDIDATES

Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
1790 Eng.	Hdw. Inj. lines	0			
1790 Eng.	Misc. Fittings	0			
1790 Eng.	Misc. Hardware, Nottle	0			
1790 Eng.	Flange Camshaft Sleeve	10865283	STL, 1009 TO 1020	2	I
1790 Eng.	Bracket, Angle	10865316	STL, QQ-S-698	1	I
1790 Eng.	Support, Fuel Injection	10865331	STL,1018,1020,1022; QQ-S-633	1	i
1790 Eng.	Support, Fuel Injection	10865332	STL,1018,1020,1020; QQ-S-633	1	I
1790 Eng.	Plate, Fuel Injection Lines	10865334	STL, 1018, 1020,1022 ; QQ-S-633	2	I
1790 Eng.	Support, Fuel Injection	10865335	STL,1018,1020,1022; QQ-S-633	2	I
1790 Eng.	Bracket, Angle	10865375	STL, QQ-S-698	2	I
1790 Eng.	Hose, Assembly Telfon	10865437	STL, Nut	3	2
1790 Eng.	Bracket, Handle	10868316	STL, QQ-S-698	1	I
1790 Eng.	Bracket Angle	10882766	STL, QQ-S-698	3	1
1790 Eng.	Neck, Oil Filler Tube	10935619	STL, Iron Class 3; MIL-I-11444	2	I
1790 Eng.	Spacer, Sleeve	10965478	STL, 1020, 1022 OR 1025	2	I
1790 Eng.	Bracket, Cooling Fan Spt.	11682768	STL, HRCO P&O OR CR Temper 3-5	2	II
1790 Eng.	Bracket, Cross Shaft	11684020	STL, Cast G II; QQ-I-666	1	I
1790 Eng.	Sleeve, Flanged	11684106	STL, 1212, B1112 OR 12L14	2	II
1790 Eng.	Bracket Angle	11684128	STL, 1018-1025	3	II
1790 Eng.	Support, Fuel Line Clamp	11684160	STL, 4130; QQ-S-624	2	II
1790 Eng.	Bracket Cooling Fan Shd.	11684234	STL, HRCO P&O OR CR Temper 3-5	2	II
1790 Eng.	Housing, Solenoid	12254204	STL, Cast; QQ-i-666	3	II
1790 Eng.	Bracket Cooling Fan Spt.	12254292	STL, ASTM A109, A366, A569	2	II
1790 Eng.	Spacer	12254297	STL, 1010 TO 1020	2	I
1790 Eng.	Bracket, Solenoid	12275712	STL, ASTM A109, A366, A569, A619	2	I
1790 Eng.	Lever	8761111	Iron, Cast; MIL-I-11444	2	I
AGT 1500	Couplins	0107-2-2			
AGT 1500	Elbow	3101-2-6			
AGT 1500	Misc. Hdw. (container)	9999			
Eng. Room	Misc. Hardware	0			
M1	Filler, neck, fuel cell	10861293	STL	3	II
M1	Strainer element,	10933071	STL, Cloth Wire	1	II
M1	Spring, compression	11639534	STL, Music Wire	2	II
M1	Spring	11639534			
M1	Knob	12273426	Brass	3	II
M1	Knob	12273426			
M1	Control Cable Assy.	12273428-1	STL, Carbon	3	II
M1	Control Cable Assy.	12273428-2			
M1	Control Cable Assy.	12273440	STL, Carbon	3	II
M1	Strap, Retaining`	12273716-2	STL, ASTM - A569 or A366	1	II

Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Strap, Retaining	12273716-3	STL, ASTM - A569 or A366	1	II
M1	Mount Assy	12273721	STL, 1010 to 1020	2	II
M1	Retainer Bearing	12273800	STL, Cast, QQ-S-681	2	II
M1	Clamp	12273826	STL, QQ-S-698	2	II
M1	Clamp	12273827	STL, QQ-S-698	2	II
M1	Bracket	12273867	STL, QQ-S-698	2	II
M1	Washer, Thrustt	12273919	STL, 4130 OR 8630	2	II
M1	Spring, Compression	12273922	STL, Wire, QQ-W-412	2	II
M1	Shoe Assy.	12273923	STL , 4130 OR 8630	2	II
M1	Mount Assy.	12274555	STL	2	II
M1	Spring	12274757	STL, Spring Wire, QQ-W-428	2	II
M1	Hook	12275001	STL, ASTM A517	3	II
M1	Handle,Assy.	12275018-1	STL, 1015 TO 1025	2	II
M1	Clip	12275087	STL, QQ-S-698	2	II
M1	Handle	12281644	STL, 1015 TO 1025	2	II
M1	Bushing	12281815	STL, 1015 TO 1025	2	II
M1	Spacer	12282674	STL, Tube; 4130 or 8630	2	ii
M1	Spacer	12282780	STL, Tube; MT 1010 TO MT1020	2	II
M1	Knob	12282908	STL, 1015 TO 1025	2	II
M1	Handle	12282984	STL, 1015 TO 1025	2	II
M1	Spacer	12283011	STL, 1015 TO 1025	2	II
M1	Spring	12283016	STL, Music Wire, QQ-W-470	2	II
M1	Plunger, Assy.	12283025	STL	2	II
M1	Clamp	12283048	STL, 1015 TO 1025	2	I
M1	Nut, Adaptor	12283081	STL, 1015 TO 1025	2	II
M1	Nut, Adaptor	12283082	STL, 1015 TO 1025	3	II
M1	Tube Assy.	12283089	STL, MT 1010 TO 1020	2	II
M1	Rod	12283091	STL, 1015 TO 1025	2	II
M1	Clevis	12283092	STL, 1015 TO 1025	2	II
M1	Spacer	12283095-1	STL, Tube; MT 1010 TO 1020	2	II
M1	Spacer	12283095-2	STL, Tube; MT 1010 TO 1020	2	II
M1	Rod	12283096	STL, 1015 TO 1025	2	II
M1	Lever	12283097	STL, 1015 TO 1025	2	II
M1	Screen, Bilge Pump	12283099	STL, QQ-S-698	2	II
M1	Lever	12283700	STL, 1015 TO 1025	2	II
M1	Lever	12283701	STL, 1015 TO 1025	2	II
M1	Handle	12283704	STL, 1015 TO 1025	2	II
M1	Manifold	12283711	STL 1015 TO 1025	2	II

Cd - Cadmium
IVDAl - Ion Vapor Depositon of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAl as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Clamp	12283718	STL, QQ-S-698	2	II
M1	Bellcrank, Assy.	12283729	see 12283724		
M1	Lever	12283732	STL 4130 OR 8630	2	II
M1	Bushing	12283733	STL 4130 OR 8630	2	II
M1	Pin	12283735	STL 1015 TO 1025	2	II
M1	Stop	12283736	STL 1015 TO 1025	2	II
M1	Spring, Helical Torsion	12283738	STL, Music Wire, QQ-W-470	2	II
M1	Bracket	12283739	STL, QQ-S-741	2	II
M1	Lever	12283742	STL 4130 OR 8630	2	II
M1	Bracket	12283749-1	STL 1015 TO 1025	2	II
M1	Bracket	12283749-2	STL 1015 TO 1025	2	II
M1	Bell Crank	12283752	see 12283754		
M1	Spring	12283753	STL, Music Wire, QQ-W-470	2	II
M1	Block	12283757	STL, 1015 TO 1035	2	II
M1	CAM	12283758	STL 4130 OR 8640	2	II
M1	Lever	12283760	STL, ASTM A514 TO A517	2	II
M1	Arm	12283761	STL, Carbon, QQ-C-741	2	II
M1	Plate	12283763	STL, 1035 TO 1045	2	II
M1	Block	12283764	STL, 1035 TO 1045	2	II
M1	Brake Pedal Assy.	12283772	see 12283769		
M1	Plate Mounting	12283773	STL, QQ-S-698	3	II
M1	Spring, Service Brakes	12283774	STL, Music Wire, QQ-W-470	2	II
M1	Spacer Plate	12283779	STL, QQ-S-698	2	II
M1	Bell Crank Assy.	12283788	see 12283787		
M1	Rack	12283894	STL, 4140 OR 8640	2	II
M1	Lock Plate	12283895	STL, 4140 OR 8640	2	II
M1	Shaft	12283899	STL, 1030 TO 1040	2	II
M1	Cover-Left	12283912	Armour STL, Wrought	2	II
M1	Lever	12284018	STL, 4140 OR 8640	2	II
M1	Shaft	12284021	STL 1015 TO 1025	2	II
M1	Bushing	12284023	STL 1015 TO 1025	2	II
M1	Lever	12284024	STL, 4130, MIL-S-18727	2	II
M1	Clamp Core	12284025	STL 4140 OR 8640	2	II
M1	Lever	12284026	STL 4140 OR 8640	2	II
M1	Bracket	12284060	STL, Carbon, QQ-S-741	2	II
M1	Bracket	12284205	STL, QQ-S-698	2	III
M1	Bell Crank Assy.	12284215	see 12284229		
M1	Bracket	12284277	STL, QQ-S-698	2	III

Cd - Cadmium
IVDAI - Ion Vapor Depositon of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAI as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Hub	12284920	STL, 4130 OR 8630	2	II
M1	Arm	12284999-1	STL, 1015 TO 1025	2	II
M1	Arm	12284999-3	STL, 1015 TO 1025	2	II
M1	Arm	12285024	STL, Cast 1020	2	II
M1	Spring, Helical Extension	12285044	STL, Music Wire, QQ-W-470	2	II
M1	Crank	12285219	STL, 4130 OR 8630	2	II
M1	Handle	12285221	STL, Tube, MT1010 TO MTX1020	2	II
M1	Spring	12285223	STL, Wire Spring, QQ-W-428	2	II
M1	Grip, Squeeze	12285224	STL, 1015 TO 1025	2	II
M1	Bracket, ALTERNATOR	12285282	Iron, Ductile Cast	2	II
M1	Clamp, Core	12285394	STL, 4140 OR 8640	2	II
M1	Bracket	12285405	STL, QQ-S-698	2	II
M1	Bracket	12285406	STL, QQ-S-698	2	II
M1	Plate	12285408	STL, QQ-S-741	2	II
M1	Plate, Support	12285409	STL, QQ-S-741	2	II
M1	Plate, Support	12285410	STL, QQ-S-741	2	II
M1	Support	12285813	STL, 1015 TO 1025	2	III
M1	Pin	12287034	STL, 4130, 8630 OR 4140	2	II
M1	Pin, Hinge	12287035	STL, 4130 OR 8630	2	II
M1	Insert	12287067	STL 4130 OR 8630	3	II
M1	Bracket	12287365	STL, QQ-S-698	2	II
M1	Bracket, Riser	12287393	STL, QQ-S-741	2	II
M1	Track, Guide	12287420	STL, 4130 OR 8630	2	II
M1	Seal	12287436	STL, 4130 OR 8630	2	II
M1	Seal	12287439	STL, 4130 OR 8630	2	II
M1	Seal	12287455	STL, 4103 OR 8630	2	II
M1	Guide	12287461	STL, 4130 OR 8630	2	II
M1	Retainer	12287466	STL, QQ-S-698	2	II
M1	Retainer	12287470	STL, QQ-S-698	2	II
M1	Seal	12287473	STL, 4130 OR 8630	2	II
M1	Retainer	12287476	STL, QQ-S-698	2	II
M1	Seal	12287495	STL, 4130 OR 8630	2	II
M1	Retainer	12287503	STL, 1015 TO 1025	2	II
M1	Link	12287506	STL, 4130 or 8630	2	ii
M1	Bracket	12287516	STL, 1015 TO 1025	2	II
M1	Seal	12287527	STL, 4130 OR 8630	2	II
M1	Seal	12287534	STL, 4130 OR 8640	2	II
M1	Retainer	12287538	STL, 1015 TO 1025	2	II

Cd - Cadmium
IVDAI - Ion Vapor Deposition of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAI as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Guide	12287539	STL, 4130 TO 8630	2	II
M1	Roller	12287543	STL, 1015 TO 1025	2	III
M1	Guide	12287555	STL, 4130 OR 8630	2	II
M1	Support	12287581	STL, Cast	2	II
M1	Bracket	12287582	STL, QQ-S-698	2	II
M1	Knob	12287583	STL	2	II
M1	Rod End	12287586	STL, Cast	2	II
M1	Actuator	12287587	STL, Cast	2	III
M1	Slide	12287606	STL, Cast	2	II
M1	Housing	12287607	STL, Cast	2	II
M1	Pin	12287619	STL, 1040 TO 1050	2	II
M1	Bushing	12287622-1	STL, 1040 to 1050	2	II
M1	Stop	12287623	STL, 1015 TO 1025	3	II
M1	Rod, Actuator	12287625	STL, 1015 TO 1025	3	II
M1	Lock	12287626	STL, 1040 TO 1050	2	II
M1	Rod	12287627	STL, 1040 TO 1050	3	II
M1	Bushing	12287629	STL, 1040 TO 1050	2	II
M1	Spring, Helical Torsion	12287633	STL, Music Wire, QQ-W-470	2	II
M1	Handle	12287634	STL, Cast	2	III
M1	Spring	12287635	STL, 1065 TO 1095	2	II
M1	Support	12287639	STL, QQ-S-698	2	II
M1	Knob, Ball	12287644	Plastic, Optional STL, Insert	3	II
M1	Spring, Helical Comp.	12287648	STL, Music Wire, QQ-W-470	2	II
M1	Guide	12287659	STL, 4130 TO 8630	2	II
M1	Guide	12287669	STL, 4130 TO 8630	2	II
M1	Arm, Drivers Control	12287737	STL, 1015 TO 1025	2	II
M1	Retainer	12287777	STL, QQ-S-698	2	II
M1	Retainer	12287787	STL, QQ-S-698	2	II
M1	Shim	12287914-2	STL, 4130	2	II
M1	Retainer	12288357	STL, 1015 TO 1025	2	II
M1	Retainer	12288358	STL, 1015 TO 1025	2	II
M1	Retainer	12288367	STL, 1015 TO 1025	2	II
M1	Retainer	12288375	STL, 1015 TO 1025	2	II
M1	Strap	12288414	STL, 1015 TO 1025	2	III
M1	Shim	12288445	STL, QQ-S-698	2	II
M1	Lock	12288511	STL, Cast 4130 or 8630	2	II
M1	Retainer	12288531	STL, QQ-S-741,1015 TO 1025	3	II
M1	Support	12288549	STL, QQ-S-741	2	II

Cd - Cadmium
IVDAI - Ion Vapor Depositon of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAI as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Spring	12288580	STL , Music Wire, QQ-W-470	3	II
M1	Plunger	12288589	STL, 4130 OR 8630	2	II
M1	Bracket	12288595	STL, 1015 TO 1025	2	II
M1	Support	12288635	STL, 1015 TO 1025	2	III
M1	Support	12288637	STL, 1015 TO 1025	2	III
M1	Pedal Assy.	12288640	see 12288599		
M1	Bracket	12288680	STL, QQ-S-741	3	II
M1	Lever Assy.	12288681	STL 1015 TO 1025	3	II
M1	Stop Assy.	12288682	STL, 1015 TO 1025	3	II
M1	Plate	12288751	STL, QQ-S-698	2	II
M1	Bushing(Spacer)	12288779	STL, Tube MT1010 to MTX1020	3	II
M1	Spring	12301595	STL, Music Wire, QQ-W-470	2	II
M1	Handle	12301803	STL, 1015 TO 1025	2	II
M1	Bracket	12301825	STL, QQ-S-698	1	I
M1	Handle	12301826	STL 4130 OR 8630	2	II
M1	Plate, Adapter	12304528	STL, QQ-S-698	2	I
M1	Bracket	12304536	STL, QQ-S-741	2	II
M1	Spring, Helical Ext.	12304635	STL Wire, ASTM A401	3	I
M1	Pulley	12304640	STL, 1018 TO 1030 OR Cast 1020	2	II
M1	Spring, Helical Ext.	12304641	STL, Wire, ASTM A401	3	I
M1	Tube	12304644	STL, Tube MT 1010 TO MTX 1020	2	II
M1	Bracket	12304666	STL, QQ-S-698	2	II
M1	Retainer	12310647			
M1	Strap	12310742	STL, 1015 TO 1025	2	III
M1	Arm	12310975	STL, Cast	2	II
M1	Spring	12311037	STL, Wire TI; QQ-W-428	2	II
M1	Bracket	12312064	STL, QQ-S-698	2	II
M1	Tube	12312072	STL, Tube, MT 1010 TO MTX1020	2	II
M1	Pin	12312102	STL, 1015 TO 1020	2	II
M1	Bracket	12312104	STL, QQ-S-698	2	I
M1	Arm, Drivers Control	12312105	STL, 1015 TO 1020	2	II
M1	Plug Assy.	12312119	STL, 1015 TO 1025	3	I OR II
M1	Spring	12312209	STL, 1015 TO 1025	2	II
M1	Tube Assy.	12312299	STL, 1015 TO 1025/MT1010-MT1020	2	II
M1	Handle, Lifting	12312319	STL, 1015 TO 1020	2	II
M1	Crank	12312429	STL, 4130 OR 8630	2	II
M1	Plate	12312791	STL, Carbon	3	III
M1	Plate	12312792	STL, 1015 TO 1025	2	II

Cd - Cadmium
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STL - Steel
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Bracket	12315776	STL, ASTM-A569 TO A366	2	II
M1	Support, Retainer	12316316	STL, ASTM-A569 OR A366	2	II
M1	Mount, Engine	12316326	STL, 4130 OR 8630	2	II
M1	Cover, Block Assy.	12316367	STL, 1015 TO 1025	2	II
M1	Cap, Fuel	12316370	STL, 1065, 1075 - 1085	2	II
M1	Bracket	12321601	STL,1065 - 1025	2	II
M1	Plate	12322253-3	STL,ASTM - A569 or A366	2	II
M1	Strap (Retainer)	12322325	STL, 1015 TO 1025	2	III
M1	Strap (Retainer)	12322332	STL, 1015 TO 1025	2	III
M1	Strap (Retainer)	12322343	STL, 1015 TO 1025	2	II
M1	Coupling Assy.	375209-8			
M1	Coupling, Half	375507-8			
M1	Drain Cock	543851			
M1	Lampholder	8694458	STL	2	II
M1	Bolt	8710628	Grade 8, FF-8-575	3	II
M1	Shaft	8710629	STL6150,2142,8645	2	II
M1	Bushing	AN912-1K			
M1	Nut	BHM-10			
M1	Connector	D80137-J-08			
M1	Sleeve	MS17796-54			
M1	Pin	MS17984-C832			
M1	Pin	MS17984C508			
M1	Pin	MS17984C609			
M1	Pin	MS17984CB12			
M1	Reducer	MS21916J12-8			
M1	Elbow	MS24519-1			
M1	Spring	MS24585-1341			
M1	Spring	MS24585-1408			
M1	Spring	MS24585-1408			
M1	Spring	MS24585C313			
M1	Spring	MS24586-C47			
M1	Spring	MS24586C109			
M1	Spring	MS24586C189			
M1	Spring	MS24586C48			
M1	Dummy connector	MS3115-14A			
M1	Plug	MS49005-2C			
M1	Plug	MS49005-4			
M1	Elbow	MS51839-6SS			

Cd - Cadmium
IVDAl - Ion Vapor Depositon of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAl as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M1	Nipple	MS5184-6SS			
M1	Adapter	MS51843-6SS			
M1	Elbow	MS51852-5SS			
M1	Elbow	MS51852-9SS			
M1	Plug	MS51884-73			
M1	Plug	MS51884-7C			
M1	Cap	MS51890-6SS			
M1	Cap	MS51890-6SS			
M1	Screen	P14-2849			
M109	Shaft Output Final Drive	10936276			
M110	Shaft Assy. Final Drive	8351828			
M174	Rod Center Recoil Cyl.	10901204			
M174	Rod Piston	10956584			
M48	Misc. H-Ware & Turret	0			
M48	Gun H-Ware	0			
M48	Rack Sleeve	0			
M48	Hardware	0			
M48	Cable Hardware	0			
M48	Bracket	10916688	STL, Cast, G5-35	2	II
M48	Connector, Cable	10923720	STL 1015 TO 1025	2	II
M48	Clevis	10924481	STL, 4130 TO 4140 OR 8630 TO 8640	3	II
M48	Rod End Clevis	10924482	STL, 4130 TO 4140 OR 8630 TO 8640	3	II
M48	Lever	11615367	STL, G rade-B OR C, QQ-S-741	2	II
M48	Lever	11615378	STL, 1015 TO 1020	2	II
M48	Support Assy.	11615380	STL, 4140 OR 4130	3	II
M48	Lever	11615381	STL, 1015 TO 1025	2	II
M48	Clevis	11615391	STL, 1015 TO 1025	3	II
M48	Clevis	11673808	STL, 1015 TO 1025	3	II
M48	Rod End Self Aligning	7388852	STL, 4140 OR 4130	1	II
M48	Clip, Retaining	7769828	STL, QQ-W-428	3	II
M48	Retainer	8370444			
M48	Driver's Door Handle	8370445			
M48	Door Plate	8386885			
M48	Arm	8388885	STL, C 1015 TO 1025	2	II
M48	Link	8744417			
M48	Hatch Handle	9999			
M48	Retainer Ring	MS16625-1300			
M48	A/C Plug	MS2091-3J			

Cd - Cadmium
IVDAI - Ion Vapor Deposition of Aluminum
STL - Steel
This list contains components which are candidates for the application of IVDAI as an optional final protective finish.
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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M48	Clevis	MS35812-4			
M48/60	Handle, Pull	10941006	STL, 4140 OR 8640	2	II
M48A5	Drive Shaft w/Universal	10873379			
M551	Misc. H-Ware	0			
M551	Misc. clamps	0			
M551	All Hardware	0			
M551	Hardware	0			
M551	Hardware	0			
M551	Mixed Fittings & Hardware	0			
M551	Key, Torque, Recoil Gd.	10948349	STL, 8630, 4130 OR 4140	3	II
M551	Cover, Torison Bar	10948388	STL, Cast C4	2	II
M551	Trans. Mount Inserts	10948414	STL, C1040 TO C1050	1	II
M551	Trans. Mount Inserts	10948415	STL, C1040 TO C1050	1	II
M551	Anchor, Torsion Bar	10948664-1	STL, Forging, 4340 or 8745	3	II
M551	Bracket, Brake Linkage	10952803	STL, Cast C8	2	II
M551	Clevis, Rod End	10952808	STL Forging 1015 to 1030	3	II
M551	Guide, Vert. Adjust., Seat	10953409	STL, MT1010 TO MTX1020	1	II
M551	Spring, Helical Torsion	10953993	STL, ASTM -A231	3	II
M551	Housing, Suspension Arm	10956056-1	STL, Cast C120-95	2	II
M551	Clelver Bucket Latch	11574119			
M551	Handle Assy. Shift Control	11593527	STL, C1040 TO 1045	3	II
M551	Pin, Adjusting, Pivot	11635463	STL 1018 TO 1045	3	II
M551	Ring, Grenade Launcher	11636383	STL, Cast, G 65-35;QQ-S-681	3	II
M551	Grenade Launcher Tube	11643674	STL, Cast G 105-85;QQ-S-681	2	II
M551	Bar, Access Cover	11644515	STL 4140 TO 4150	3	II
M551	Plunger, Door Latch	11644545-1	STL, 4140 TO 4150	3	II
M551	Plunger, Door Latch	11644545-2	STL, 4140 TO 4150	3	II
M551	Escape Hatch Lever	11644571	STL, Cast C65-35	2	II
M551	Shock Absorbing, Fuel Tk.	11652657	STL 4140, 8640 OR 8740	2	II
M551	Plug, Grease, Arm	11653005	STL, 1018 TO 1035, 1108 TO 1137	3	II
M551	Connector, Male	11683952	Iron, Cast; QQ-I-666	2	I
M551	Recoil Guard Key	7404673			
M60	Turret Ring Bolts	0			
M60	Gun H-Ware	0			
M60	Misc. Hardware	0			
M60	Misc. Parts, Fuel Control	0			
M60	Mixed Hardware	0			
M60	Cable Hardware	0			

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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M60	Tow Pintel Nut and Pins	0			
M60	Rod Clevis	10863525	STL, Cast C 65-35	2	II
M60	Universal Joint	10863537	STL	2	II
M60	Universal Joint	10863538	STL	2	II
M60	Wedge, Prism Lock	10873206	STL, Forging, 1020 to 1045	2	II
M60	Bracket, Mounting	10886812	STL, 1015 TO 1025	2	II
M60	Handle	10911402			
M60	Hnadle, Turret Lock	10912137	STL, Cast, C1020; MIL-S-22141	3	II
M60	Brake Pedal	10915240	STL, Castc C 65-35	2	II
M60	Seat Spring	10933600	STL, Wire	2	II
M60	Bracket,Trans Mount	10934034-1	STL, Cast C105-85	2	II
M60	Bracket,Trans Mount	10934034-2	STL, Cast C105-85	2	II
M60	Plate	11610563	STL, 1015 TO 1025	2	II
M60	Bell Crank Assy.	11626368	see 11626369		
M60	Lever, Brake	11659175	STL, 4130, 4140 OR 8630, 8640	2	II
M60	Strap Blower Motor	12251905	STL, QQ-S-698	2	II
M60	Support Blower	12251912	STL, QQ-S-698	2	II
M60	Spring	12252067	STL, ASTM-A401	2	II
M60	Spring	12252142	STL, Music Wire,MT1010 to MTX1020	3	II
M60	Handle	12257495	STL	2	II
M60	Rod End Self Aligning	7388852	STL	1	II
M60	Rod End Self Aligning	7388852	STL	1	II
M60	Plate, Drivers Seat Ret.	7404660	STL, QQ-S-640	2	II
M60	Retainer, Drivers Flange	7404661	STL, Tube 1000 to 1025	1	II
M60	Spring, Gunners Seat	7985147	STL, Wire Comp. A-B; QQ-W-474	2	II
M60	Mount Machined	8619454	STL, Cast C65-35	2	II
M60	Support	8619488	STL, Cast C65-35	2	II
M60	Valve	8724467	STL, Forging 8630, 4130 8625	1	II
M60	Knob	8724468	Cast, Iron, C5-6; MIL-T-11466	2	II
M60	Retainer, Packing	8725184	STL, QQ-S-686	2	I
M60	Rod End Self Aligning	8741800-1	STL	1	II
M60	Drain Rod Connetor	8762659			
M60	Rod Guide	8762659			
M60	Lever	8762765			
M60	Housing, Burner Cup	G706039			
M60	Interuptor Bkt. Pin	MS17984817			
M60	Clevis	MS35812-4			
M60A3	Misc. clamps	0			

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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M60A3	All Hardware	0			
M60A3	Door Hardware & Plate	0			
M60A3	Hardware	0			
M60A3	Tube,Oil Pan Drain,inlet	10865022	STL, Tube MT1010 TO MTX1020	2	II
M60A3	Bolt, Eye	10893633	STL, Forging 4130 or 8630	3	I
M60A3	Tube, Slotted	10941008	STL, Tube, MT1010 TO MTX1020	3	II
M60A3	Air Cleaner Washers	11571586			
M60A3	Fuel Pump Clamps	11608045			
M60A3	Cover, Access	11637079	STL, QQ-S-698	2	II
M60A3	Bracket Housing	11682615	STL, HRCO P&O OR CR Temper 3-5	2	II
M60A3	Oil Cover Flange	11683452			
M60A3	Guide Engine, Inst.	11684008	STL, ASTM A36	2	II
M60A3	Oil Cover Flange	12254580			
M60A3	Bracket Mounting	12295070			
M60A3	Pin, Cable Tow	5213744	STL, Wire, QQ-W-428	2	II
M60A3	Flat Washer: Crank Case	5725170			
M60A3	Tee	6-381-1			
M60A3	Flange Nut	6295380	STL, Tube, 4140 TO 8640	2	II
M60A3	Tow Pins	7069175			
M60A3	Shaft Intake Tube	732049			
M60A3	Injection Pump base	761085			
M60A3	Nut, Slotted, Special	7767723	STL, C 8640, 8740 OR 4140	3	I
M60A3	Hydraulic Shaft	7974225	see 797433		
M60A3	Plate, Drivers	8386885	STL, Cast C65-35	2	II
M60A3	Adaptor, Trans. Case	8682736	STL, SAE 1035 OR 1040	3	I
M60A3	Cover, FDH	8682765	Iron, C5 or C7 ; MIL-I11444	3	I
M60A3	Plug, Arm, Spindle	8688986	STL, 1015 TO 1025	2	II
M60A3	Rod End Bearing	8741800-1			
M60A3	Adaptor, Cooling Fan	8761050	STL, AMS 6382	2	II
M60A3	Eye, Engine Lifting	8761080	STL, C1010 TO C1020 ;QQ-S-633	2	II
M60A3	Bolt, FLUID Pres. Line	8761091	STL, BAR, 1137 TO 1141; QQ-S-637	3	I
M60A3	Washer (Fan)	8761230	STL, 8640,8740 OR 4140	2	I
M60A3	Lifting Eye, Damper End	8761245			
M60A3	Adapter, Straight, Pipe	8761555	STL, 1010 TO 1020	2	II
M60A3	Cock Drain	9999			
M60A3	Elbow (water separator)	9999			
M60A3	Camshaft Support	9999			
M60A3	Tee (water separator)	AS25228			

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Assembly	Name	Part No.	Material	Coating Class Cd	Coating Type Cd
M60A3	Washer (container)	MS3533850			
M60A3	Nut (container)	MS51967-20			
M60A3	Screw (container)	MS90725-165			
M728	Turret Ring Bolts	0			
M728	Gun H-Ware	0			
M728	Pin, Straight Headed	10940367	STL, 4340, 4140, 8640 OR 8740	1	II
M728	Interuptor Bkt. Pin	MS-17984-817			
M88	Misc. Hardware	0			
M88	Misc. parts, Fuel Control	0			
M88	Mixed Hardware	0			
M88	Mixed Fittings	0			
M88	Rod End Self Aligning	7388852	STL	1	II
M88	Rod End Bearing	8741800-1			
M88	Housing Vent Air	G705292			
Machine	Hub, Engine, Coolant	8682785			
P7	Shaft BrakeArm	2584159			
P7	Shaft Sleeve Input	2584238			
P7	Shaft Final Drive	2584466			
P7	PTO Yoke	2587621			

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